TECHNICAL ORDER NO. 30-100D-1

INSTRUMENT FLYING

Technique in Weather

1 JAN 1944

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Foreword

In this manual our hero, "fool for luck" and principal character, is Scratchy. Scratchy is an average pilot. He has average skill and his reflexes are about the same as yours. He got his name during his cadet days because he could not work a problem without scratching his head. When he began to think, he began to scratch.

Thinking is a useful exercise, and frequently Scratchy scratched out the right answers. By the time he became a pilot it seemed to him that he had scratched out every possible answer. He could fly from the seat of his pants, so when he came up against the problems of efficiency and safety in flying weather, he hardly scratched at all. This was his mistake. It was a mistake in 12 parts, each the result of insufficient preliminary scratching.

What they added up to was a lesson he won't soon forget. It is a lesson every pilot has to learn, somehow. Like Scratchy, he may be able to barge ahead, learn it the hard way, and do his thinking afterward. Scratchy no longer recommends this course. He says you ought to sit down with this manual and let it help you to do your thinking first.

If you don't do your thinking about flying weather first, you'd better be sure you were born lucky.

Section I

SCRATCHY LIVES TO TELL ABOUT IT

Scratchy's orders were to proceed from Sherman Field to Hensley, flying a P-40. This was good news; he had been at the field nearly a week with no chance to fly. The sergeant told him his ship was warming up, so he didn't lose a minute. He tore into the locker room, grabbed his parachute bag and flying suit. With his arms full, he rushed to the operations office to make out his clearance. At the door he nearly knocked over the weather officer who was leaving for lunch. Scratchy was inside before it occurred to him that he ought to find out about the weather. He dumped his stuff by the wall and dashed out again. "Lieutenant Warner!" he said, "How's the weather to Hensley? I'm going right away. What's the best altitude?"

As far as Lieutenant Warner knew, all pilots were going right away, and they had to know everything instantly. However, he thought it was important for them to get it right, so he said, "Better see Sergeant Farnum in the office. It was all right this morning but it will be clabbering up soon."

"It's only 3 hours flying," Scratchy said. "I guess I could get there before it socks in."

Lieutenant Warner didn't think much of offhand guesses. "It won't hurt to take a look at the map. The sergeant will go over it with you," he said.

Scratchy ducked back into the operations office, filled out his clearance form, and took it into the base weather station. He flipped casually through the latest weather sequences while the forecaster on duty wrote the weather paragraph on the clearance, and glanced at the forecast.

Scattered to broken clouds over Missouri becoming overcast in Oklahoma, Ceiling 2 to 4,000 with occasional rain showers developing after 1300 CWT. Winds aloft 150 degrees 15 to 20 miles an hour at 3,000 veering to 270 degrees at 8,000.

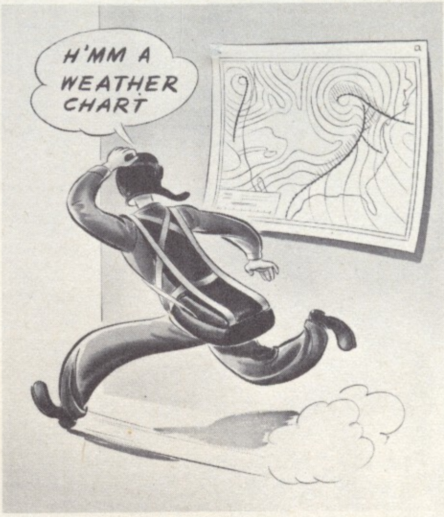
"I'd settle for that any day," thought Scratchy.

At this moment Sergeant McGinty, who had been servicing Scratchy's plane, called through the door, "She won't rev up on the right mag, Lieutenant. We're checking the plugs."

ALWAYS EAT BEFORE YOU GO

Scratchy looked at his watch. Pulling the plugs would take 20 or 30 minutes. It was just noon; they always told you to eat before you left, so he decided he might as well grab something. He was halfway to the Officers' Club when Sergeant McGinty overtook him. "Found it, Lieutenant. Loose connection on No. 4 plug. She's all set to go."

Scratchy debated a moment whether to eat or not. He remembered that Lieutenant Warner had said something about lowering conditions. If he wanted to beat them, the sooner he started the better. Going back to operations, Scratchy stuck his head in the weather office. "Is Hensley contact?" he asked Sergeant Farnum.



The Sergeant stepped to the display counter and looked at the latest reports. He said, "It's O.K. now, sir; but there's a warm front between Dallas and Oklahoma City. Ceiling's lowering, and you might have trouble keeping contact through the front. The top of the stratus is around 4,000 feet. At 6,000 you ought to be between layers most of the way with showers in the front. You'll break out again at about 50 miles south of Oklahoma City."

"Thanks," said Scratchy. He grabbed up his papers and ran out to the ramp.

SCRATCHY'S 12 MISTAKES

"Checks okey on both mags," Sergeant McGinty told Scratchy when he reached the P-40. "Shall we top off your tanks, sir?"

"Skip it," Scratchy said. "There'll be enough."

Scratchy climbed in and adjusted his parachute. While he pulled his gloves on he made a casual inspection of the instruments and controls. He pushed the starter button and the motor caught instantly. It sounded good. With that much power in front of you, it was hard to believe that there was anything you couldn't handle. This is a delusion peculiar to inexperienced pilots, and Scratchy enjoyed it for a minute or two before the engine temperature reached the green mark. He signaled for the chocks to be pulled. "Bags in the plane!" Sergeant McGinty shouted above the roar of the engine as he signaled all clear.

AND AWAY WE GO!

Over Leavenworth at 4,000 feet, Scratchy was over scattered cumulus with patches of altostratus high above. This made for comfortable flying, without too much sun. He was right on his flight plan, with the Baldwin City radio fix right ahead to check on. A few minutes more and he would pick up the Chanute range. Scratchy snapped on his radio to get the next weather broadcast and reached for his maps and radio range list.

The maps and Radio Facility charts were not there.

Scratchy gave his head a scratch. The maps might be back in operations or in the weather office. Sergeant McGinty might have put them in with the baggage.

The fact remained that scratching wouldn't give him the frequency of the Chanute radio range. However, he knew he must be getting close, so he spun the coffee grinder until he picked up a strong "CZ." Presently the scheduled broadcast came on; not much change in the weather from what he remembered of the last sequence. Scratchy decided to stay at 4,000 feet on a 190-degree heading. So far so good.

WHERE NEXT?

After passing over the Chanute, Kansas, radio range station, near Coffeyville, the cloud cover below Scratchy gradually closed in and true to the forecast, he found himself on top of a solid stratus cloud deck.

With only occasional glimpses of the ground, Scratchy kept his radio tuned to Chanute and held in the "A" twilight of the Chanute range after passing the station. The signals soon faded. With no radio range list, Scratchy could only thumb the dial hoping to pull in the Tulsa signal. He held his original heading, but he had to climb to stay on top of the thickening clouds below him.

Scratchy was still feeling for the Tulsa frequency when the cloud layers above and below suddenly converged ahead and he found himself in a heavy rain shower. With the first dash of water on his windshield, his safety belt yanked hard against his legs as the ship fell in a down draft. He was down to 3,000 feet before he could check his descent and start to regain altitude. The ship bounced around a good deal, but

Scratchy was able to hold somewhere near his original heading. He hoped that he would soon run out of the rain, but, at 4,000 feet again, the rain was still getting heavier.

Several minutes passed with no improvement, and Scratchy thought it was about time to turn back. He was just waiting for the second hand on the clock to come up to an even minute before starting a procedure turn, when he broke out of the rain and rough air and found himself between layers which appeared to diverge ahead.

Confident that he was through the front with all the bad weather behind him, he again fiddled with the radio trying to pick up the Tulsa range. He turned the dial to the lower limit, then back again. At 245 kilocycles a strong "N" beat in his earphones and then the dash and three dots that identified the Tulsa range.

The visibility was not too hot, with a gray murky look to the clouds ahead. A tattoo of light rain on the windshield got him to thinking that perhaps not all the weather was behind him. And, in a short time he was "on instruments" sure enough. Static started to sizzle through the Tulsa range signal and rapidly built up to obliterate it.

Although the murk got noticeably darker, Scratchy barged ahead, hoping for a break in the clouds that would mark the far side of this second shower. The turbulence got worse, however, and for a long minute or so Scratchy had his hands full keeping the plane somewhere near right side up. Still no break. A little alarmed, he decided he would have to do something drastic to get in the clear. He reset his gyro as best he could and swung around sharply, heading northward to where he felt sure he could find contact weather again, or at least escape the turbulence that was tossing him around.

WHAT NEXT?

Just as he was leveling out, Scratchy noticed that his engine seemed to be losing power. As the manifold pressure dropped down below 30 inches, he instinctively moved the carburetor heat control lever toward full heat. He swore at himself under his breath for being so preoccupied with the Tulsa range as to forget about carburetor ice. It was all right this time, the sort of thing any pilot might forget. Nevertheless, the oversight shook his confidence.

He was now on a reciprocal heading, but he did not, as he expected, break out between cloud layers. At 6,000 feet, on instruments, he tuned in Chanute again. Radio reception continued poor because of the rain static, so he continued to climb. He noted that the ship's heading was 10 degrees; and having failed to break out at 10,000 feet, he supposed that this was because the upper cloud deck had lowered. Besides, the the air temperature was down around freezing, and that meant ice. Apparently there was no way out through the top. But maybe he could get out underneath; so he nosed down.

At 3,000 feet he was still on instruments, flying in light rain. By the clock, he had now been flying blind for nearly 30 minutes. As to his actual position, he could only think back and try to remember how long he had held each heading. Memory work of this sort was not easy while flying a hot ship through rough air. Scratchy soon gave it up and tried once more to pick up the Chanute radio range in the hope of working an orientation on it. The static wasn't quite so bad now, and he heard the Chanute signal growl hoarsely through the static. Relieved, he told himself that he was all right after all. Catching his breath, he realized suddenly how confused and downright scared he had been to find himself lost, on instruments, in rough air. Though he hated to admit it, he was still a bit scared.

HERE WE GO 'ROUND THE MULBERRY BUSH

Scratchy figured roughly that if he had held his 190-degree heading he would have been past Oklahoma City by this time. He must have turned around somewhere near Tulsa so he couldn't be far from Chanute. With a broad "A" signal, he turned to a heading of 90 degrees to intercept the south leg of the range. Heavy rain set in again, though, and static built up and covered the signal before he could get any background tone or be sure of a build-up or fade.

He was convinced for the moment that he was in the southwest "A" quadrant, so he turned 90 degrees left and once more headed north, hoping to run out of the rain and intercept the west leg. The clouds only got darker, and the rain and static continued heavy. Scratchy suddenly realized that he was becoming extremely tense and forced himself to relax in his seat. He looked at his clock. He had been flying for 1 hour and 40 minutes. With fuel for nearly 3 hours at take-off, he should have another hour at least, and an hour would surely see him out. If the range leg did not turn up, he would simply continue on northward toward Omaha. These calculations were abruptly interrupted by a break in the engine's rhythm. Quickly he cut in his reserve tank and gave the wobble pump several strokes; the engine resumed its normal, comforting roar. But this time Scratchy was decidedly not comfortable. The tanks had not been topped before take-off. Just how much gas did he have? Another 1/2 hour. Maybe less. Anything he was going to do he would have to do "pronto."

At this point, Scratchy was pushed solidly into his chute pad by an updraft. In 2 minutes he was tossed 2,000 feet higher. At 7,000 feet he ran out of the upward current of air but immediately the rate-of-climb indicator spun around past 2,000 feet per minute descent. He hit bottom at 4,000 feet, but only for an instant. As he started dropping again, turbulence hit him and it was all he could do to keep the plane upright. There was a distinct hollowness where his lunch should have been.

HOW HIGH IS HIGH ENOUGH?

Any thought that Scratchy had about food at that moment was not hunger. His mouth felt cottony, and inside his gloves his hands felt sweaty and not too warm. After that last drop the altimeter showed 2,500 feet. That was too low for comfort even though he was, or ought to be, over the flat country of southeastern Kansas. He felt sure that the highest ground elevation was not much above 1,000 feet and if he could trust his altimeter he ought to be all right. He tried to remember what altimeter setting had been given for Chanute on that last broadcast, but it would not come to mind. He decided that 29.92 would do. More downdrafts had brought him to 2,000 feet; there he leveled off, still in turbulent air. This, he saw, amounted to sitting there and doing nothing. That was what he must not do, so he tried feverishly to organize a plan.

"Well," he thought, "I guess I still have 1,000 feet under me. Maybe 1,500. I could let down another

500 feet and maybe break down underneath. There ought to be a cow pasture or something big enough to set this crate down in and I can't go on forever on 1/2 pint of gas. So here goes."

SCRATCHY PAYS HIS BILL

No sooner said than done. At 1,800 feet indicated, the clouds appeared darker ahead. Scratchy stared for an instant, then recognized through the rain-blurred windshield that the darkness was not just cloud. It was a small wood lot on a barren hillside.

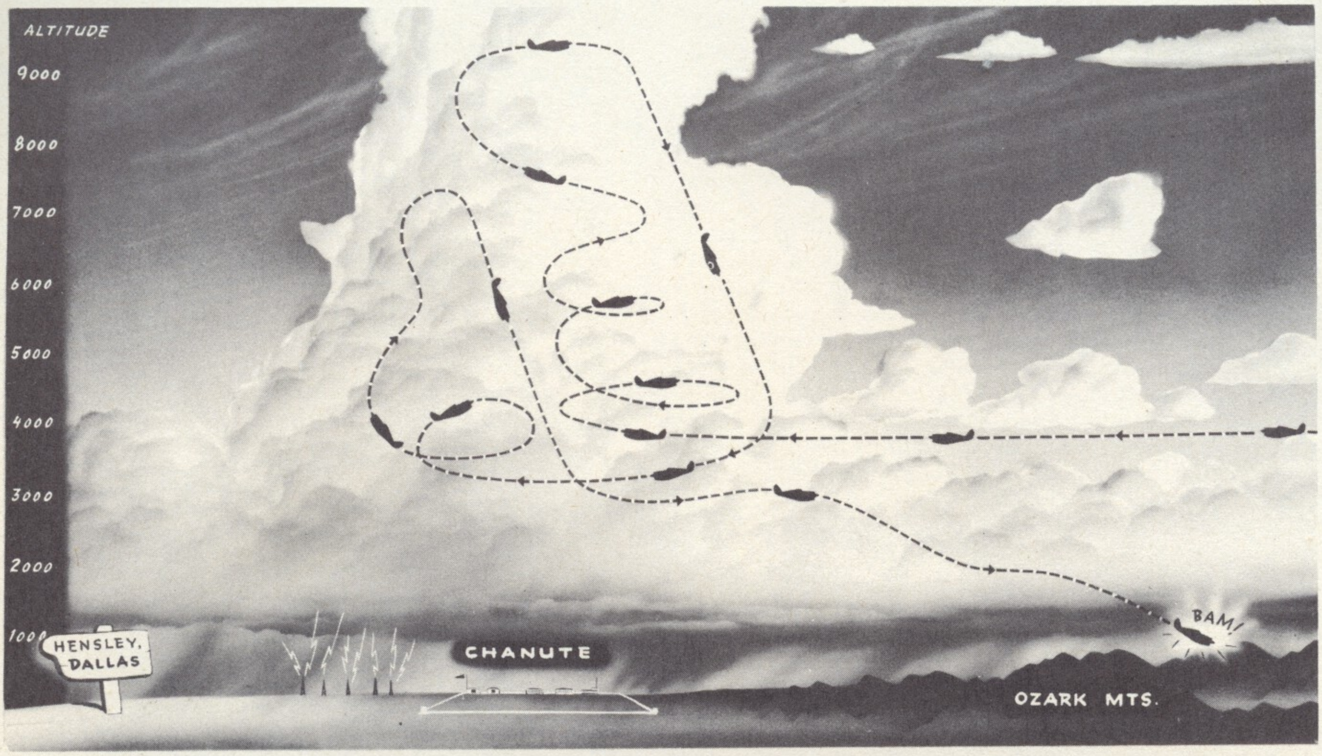
Frantically Scratchy pulled the nose up and shoved the throttle full forward. The plane zoomed upward in a steep climb and immediately the ground disappeared. Not much ceiling, that. With the altimeter hands indicating an increasingly safe altitude, he was wondering now if he could trust that instrument. It was a cinch that no trees grew 1,000 feet in the air. Something was very wrong.

Suddenly sensing a stiffening of the controls, Scratchy turned his attention to the air-speed indicator. It showed better than 300 mph. For a split second he wondered if all the instruments were crazy; and then he knew what the trouble was. While he was puzzled over the altimeter reading, he must have let his right wing drop and gone into a steep spiraling dive. Gripped now by real panic, he used full left aileron, but the P-40's response was plainly too slow. Hard left rudder brought it back on an even keel, but buffeting of the wings told him how near this maneuver had brought him to a spin. He glanced at the altimeter. Fifteen hundred feet!

YOU CAN'T WALK HOME

Scratchy didn't feel so good. With that hill, or whatever it was, around, he would be into the ground at any moment. He had to gain altitude.

Pushing the throttle forward, he pulled the nose up again. The engine failed to respond. Only intermittent



backfires answered his frantic strokes of the wobble pump. Out of gas. Gear up, switch off, flaps down, and straight ahead. There was nothing else to do.

SCRATCHY VERSUS SCRATCHY

Scratchy faced a long period of recuperation, but he knew he was lucky to be alive. He could not recall very much of what happened after he broke out beneath the ragged overcast. He could, however, recall vividly the flight from Sherman Field.

At first he tried to forget, to erase the whole humiliating business from his memory. But the more he tried to forget, the more he found himself remembering. He finally decided that the only way to find peace of mind was to review the whole flight in detail and study his mistakes.

Systematically he itemized the factors involved. He examined critically his reactions to each of those factors. At the conclusion of Scratchy's private investigation of Scratchy, only one conclusion was possible - he alone was responsible. He had his own carelessness to blame for everything that had happened to him.

Scratchy set down the several errors he had made in preparing and conducting his flight. There were 12 of them, and he was forced to marvel at his luck in escaping with his life.

Here is the list of mistakes that Scratchy drew up:

Too-hurried departure from Sherman Field.

Failure to eat lunch.

Failure to study over the weather with the forecaster.

Failure to check the fuel supply.

Failure to go over his preflight check list and make sure of his maps.

Failure to make an adequate flight plan.

Failure to stay contact when on a contact flight plan.

Failure to apply the carburetor heat before entering possible carburetor icing conditions.

Failure to make an alternate flight plan.

Failure to consider the effect of wind while milling around in the soup.

Failure to use the latest altimeter setting.

Failure to realize the hazard of letting down through an overcast over unknown terrain.

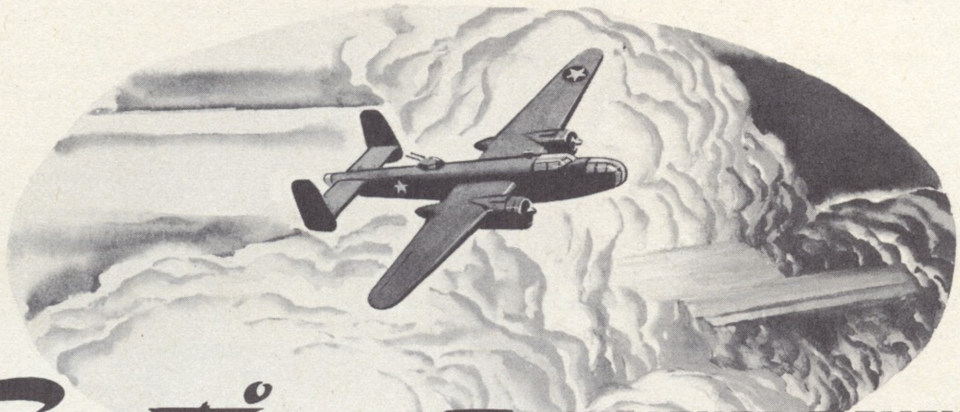
IT'S UP TO YOU

Scratchy had the common sense to realize that any one of these errors might have cost him his life. That he had escaped the combinations of 12 such errors was a tribute to his luck, he knew, not his airmanship.

Scratchy had logged more than 300 hours and passed his instrument flight test. From his hospital bed he reviewed previous flights he had made on instruments, and he was obliged to admit that he had been asking for just what finally happened. He concluded that he had tested out his luck long enough.

The doctor assured him that he would fly again. He was resolved that when that day came he would never again make an unplanned flight. He determined furthermore to develop his skill in flying in bad weather. It was a matter of technique, he decided, just as much as any other phase of flying. In the past he had not thought a weather flying technique would be necessary. Now he knew better. To take weather in stride, you had to use tried and proven tactics. He was convinced he could no longer ignore that fact.

His strategy was logical. He would review his basic weather and his air navigation together while still in the hospital. Then, once again at the controls, he would fly weather a little at a time while practicing the techniques. He would talk with other pilots whose weather sense he respected and find out what procedures they advised. He was through with flying weather by instinct alone.



Section II WEATHER ELEMENTS AFFECTING FLIGHT

As Scratchy reviewed his basic weather, it assumed a new significance. The technical terms which had been dinned into his head during his training at Randolph Field took on added meaning. He discovered that they were not just words some highbrow had thought up; they are more like instruments which a pilot must understand if he is to interpret them. A pilot who flew through weather without knowing what the forecaster had been talking about habitually flew without knowing what he was doing.

With these thoughts in mind, Scratchy sent for his text books and classroom notes and painstakingly began to study them. This time, he was interested not only in learning weather, but also in trying to get clear in his mind the possible effect of various weather elements on the actual technique of flying.

THIRD QUESTION

From his hospital window Scratchy watched the weather. He formed the habit of asking himself when he observed a change in the clouds or heard rain in the trees, "How would I fly in that particular cloud?" or, "How would I decide whether or not to fly it?" This, he realized, was what his instructor in primary training meant when he said that weather was always a question. Air navigation answers the question "Where." Practical necessities of military flying answered the question "When." Here was the third question, "How." It could be answered by study of possible plans of flight conduct in the prevailing conditions.

Thinking it out from the pilot's point of view, Scratchy classified weather elements into three broad groups by their effects on normal flight.

1. Variation of ground speed and drift.

2. Reduction of aircraft efficiency.

3. Danger to the structure of the aircraft.

CAN YOU GET THERE?

Under the first of these three headings Scratchy listed all the factors he could think of which change the speed and direction of an airplane.

1. Wind velocity at flight level.

2. Wind direction at flight level.

3. Time allowance for traffic clearance and instrument approach.

4. Time allowance for detouring bad weather.

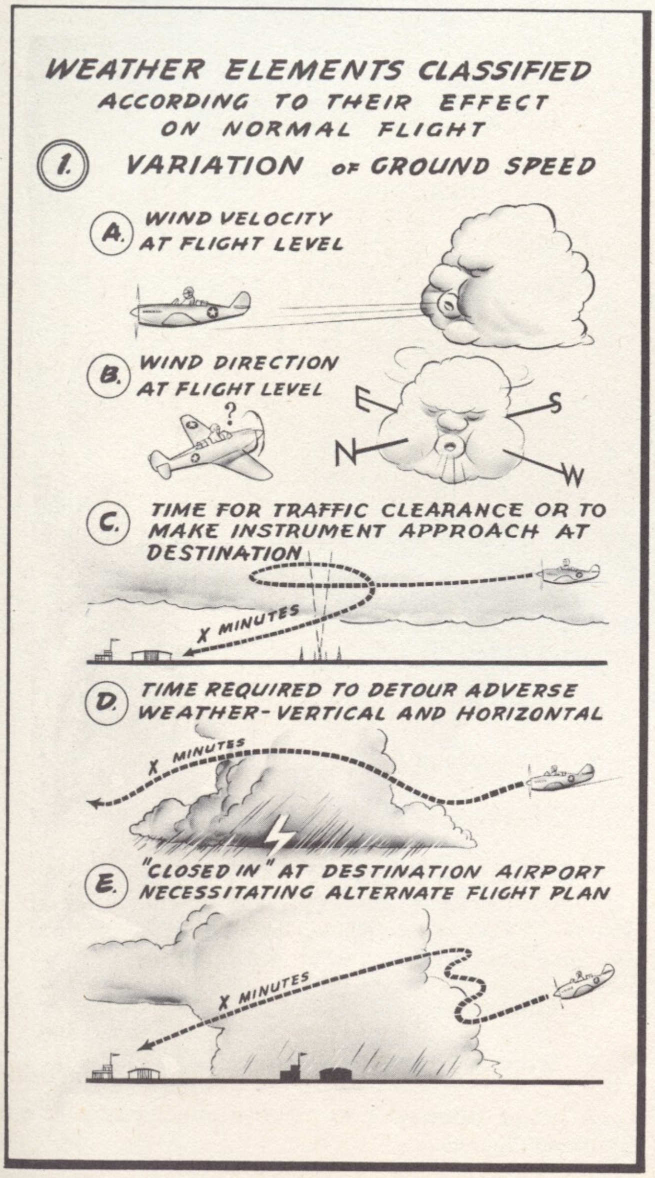
5. Closed weather at destination requiring use of alternate flight plan.

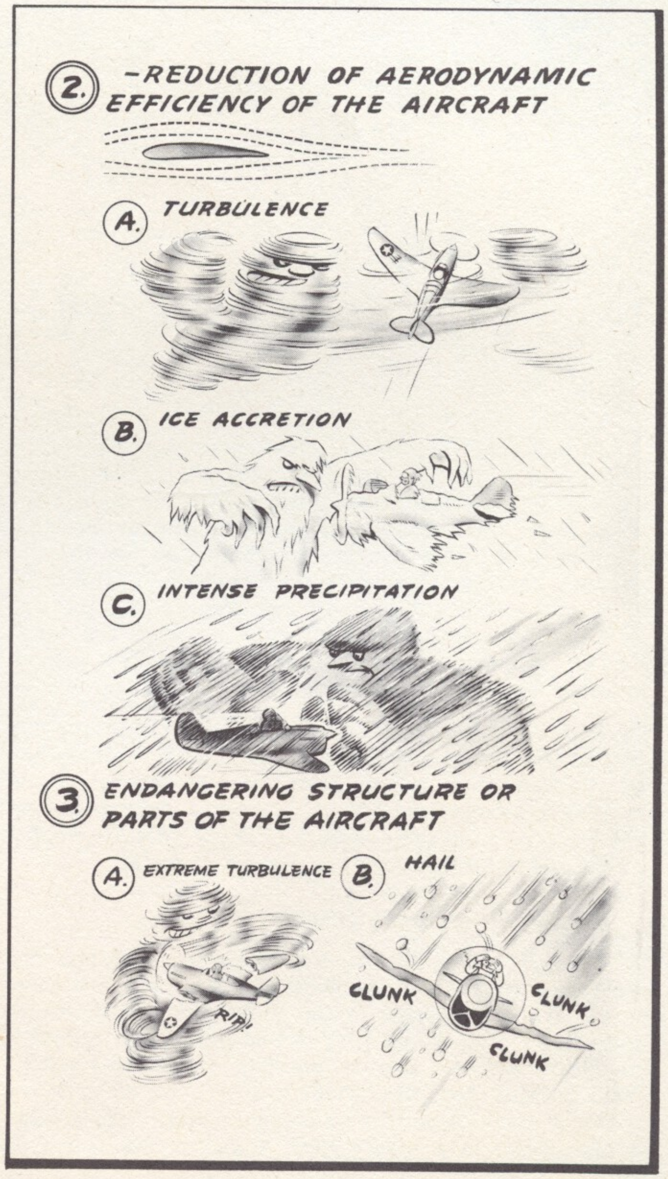
Thinking over this list, Scratchy realized that ceiling and visibility were not the whole story. As far as conditions at your destination went, you either had enough ceiling and visibility to make a safe landing, or you hadn't. If you had, you landed; if you hadn't, you followed your alternate flight plan. On the way to your destination, low ceiling and visibility along the route could make you use an instrument flight plan and might indicate the advisability of certain precautions as to the weather. Beyond that, if you were a competent instrument pilot flying a good airplane, you did not have to worry about ceiling and visibility as such.

In going over the list again, Scratchy saw that all five of the factors he had listed could usually be reckoned pretty accurately before take-off. He would have the probable wind direction and velocity in his forecast; time likely to be lost in waiting for traffic or making an instrument approach was already an old story. His alternate flight plan would be ready. With sufficient fuel and a reserve for ordinary emergencies, all the problems posed by variations of ground speed could be safely solved.

CAN YOU TAKE IT?

The second classification was that of weather elements reducing the efficiency of an airplane. Scratchy had more difficulty listing the weather elements in this category. It was mainly a process of elimination. It surprised him when he finally realized that only three factors really reduced an airplane's flyability.





1. Turbulence.

2. Ice accretion.

3. Heavy rain.

Any one of these, Scratchy knew, might be severe enough to be a real hazard unless a pilot used his head and knew something about how to meet it. Since the flying techniques to meet these hazards had already been worked out, Scratchy saw that the dangers of weather flying, instead of being vague and multitudinous as he had assumed throughout his seat-of-pants days, were really few and relatively definite. You might not be able to foresee before take-off the occurrence of turbulence, ice, or rain; but you could know the signs and be prompt in taking the proper steps. If your plane got the right kind of help from you, you could fly such weather with reasonable safety.

CAN YOU DUCK IT?

There remained the possibility of conditions which, whether you helped your plane or not, would actually endanger the plane's structure. Scratchy listed three:

1. Lightning.

2. Hail.

3. Extreme turbulence.

Scratchy had heard a lot about the hazards of lightning, hail, and very rough air; but he had never talked to a pilot who had encountered them. It occurred to him now that this was because they could be avoided with relative ease by any careful flyer. Presumably, those who were not careful were not around to talk.

CAN YOU COUNT TO TWO?

By now it was becoming apparent to Scratchy that the only two hazards which could take the airplane out of his hands were turbulence and icing conditions. The problem of weather flying is to find the means to avoid or overcome these hazards. Second only to carelessness and poor judgment, they are undoubtedly responsible for a majority of aircraft accidents. Icing and turbulence, like all other weather conditions, occur in many different forms and many different situations. The pilot must know exactly what these are and exactly what to do about them.

Section III

TURBULENCE

Turbulence is irregular motion of the air. The motion of turbulent air is made up of a series of gusts. A gust is a momentary surge of fast-moving air. It may come from any direction of the compass, or it may come upward, downward, or at an angle. Some gusts have very sharp boundaries in space, so that you fly into them with no warning whatsoever. Others are not so sharply bounded, so that you hit them more gradually. How fast the gust is going is not so important as how suddenly you hit it. Of course, a heavily loaded airplane is in greater danger than the same plane loaded lightly. Modern airplanes are designed to withstand the strain of flying fully loaded at full speed into a sharp-edged upward-moving gust of 30 feet per second. However, measurements have revealed velocities far in excess of this value in a number of isolated cases.

The flight hazards in turbulent air are:

1. Loss of control.

2. Structural damage.

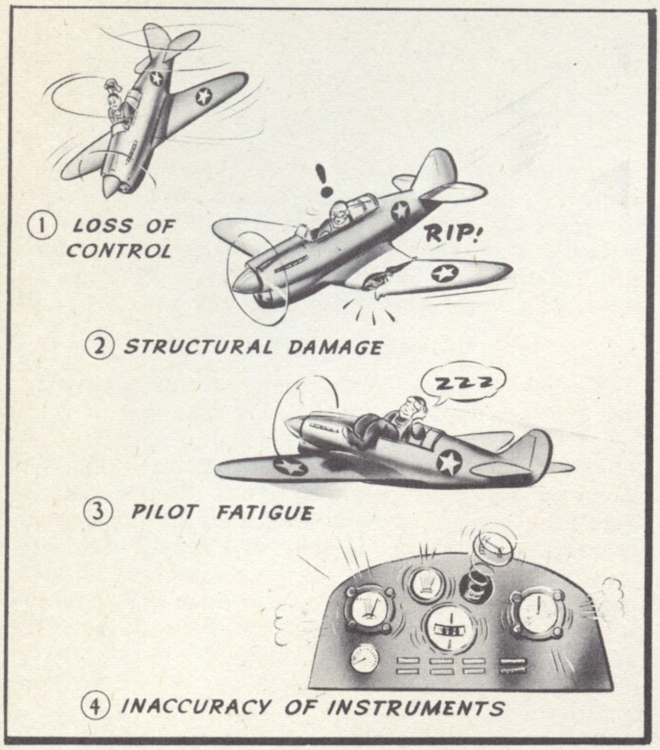
3. Pilot fatigue.

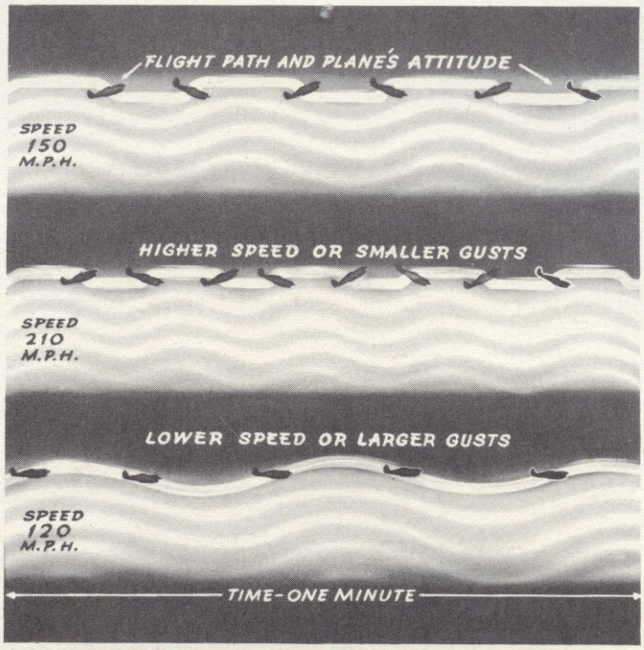
4. Inaccuracy of instruments.

NOT ALL BUMPS ARE ALIKE

There are three recognized types of turbulence:

1. Choppy or bumpy air, with small gusts close together.





This illustrates the effect on the attitude and flight path of an airplane when the frequency of turbulent motion is changed.

2. Drafts, with large, sustained gusts farther apart. These may be moving either upward or downward.

3. A combination of choppy air and draft.

In turbulent air, the possibility of loss of control can never be discounted, even when an experienced pilot is doing the flying. The technique to be used in maintaining control will depend upon the cause of the turbulence, the strength and size of the individual gusts, and the type of airplane.

Regardless of the cause or intensity of turbulence, a pilot must take into account the size and strength of the individual gusts. Variations in size and strength largely determine the flying technique to be used.

HOW TO FLY TURBULENT AIR

How you should fly to minimize danger and discomfort depends on several factors. Although there are not set rules for all conditions, the following procedures apply in a majority of cases:

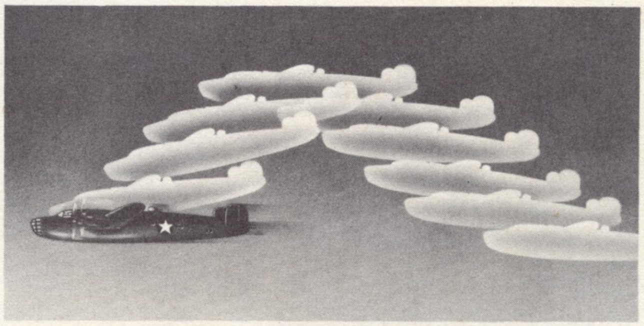
1. Reduce air speed to 50 percent above stalling speed. If the engine temperature falls too low, more power can be used at the reduced speed by lowering the landing gear.

NOTE: When flying heavily loaded aircraft or aircraft with high wing loading, the landing gear should not be lowered to avoid possible engine failure from low head temperatures. The extra drag, created by lowering the landing gear, may result in such lowered performance that a stall with loss of control might be caused.

2. Guide the control lightly, maintaining direction and air speed within reasonable limits. Do not try to correct for each gust as it hits the plane. If the plane is properly trimmed, one gust will tend to counteract another and smooth out momentary variations.

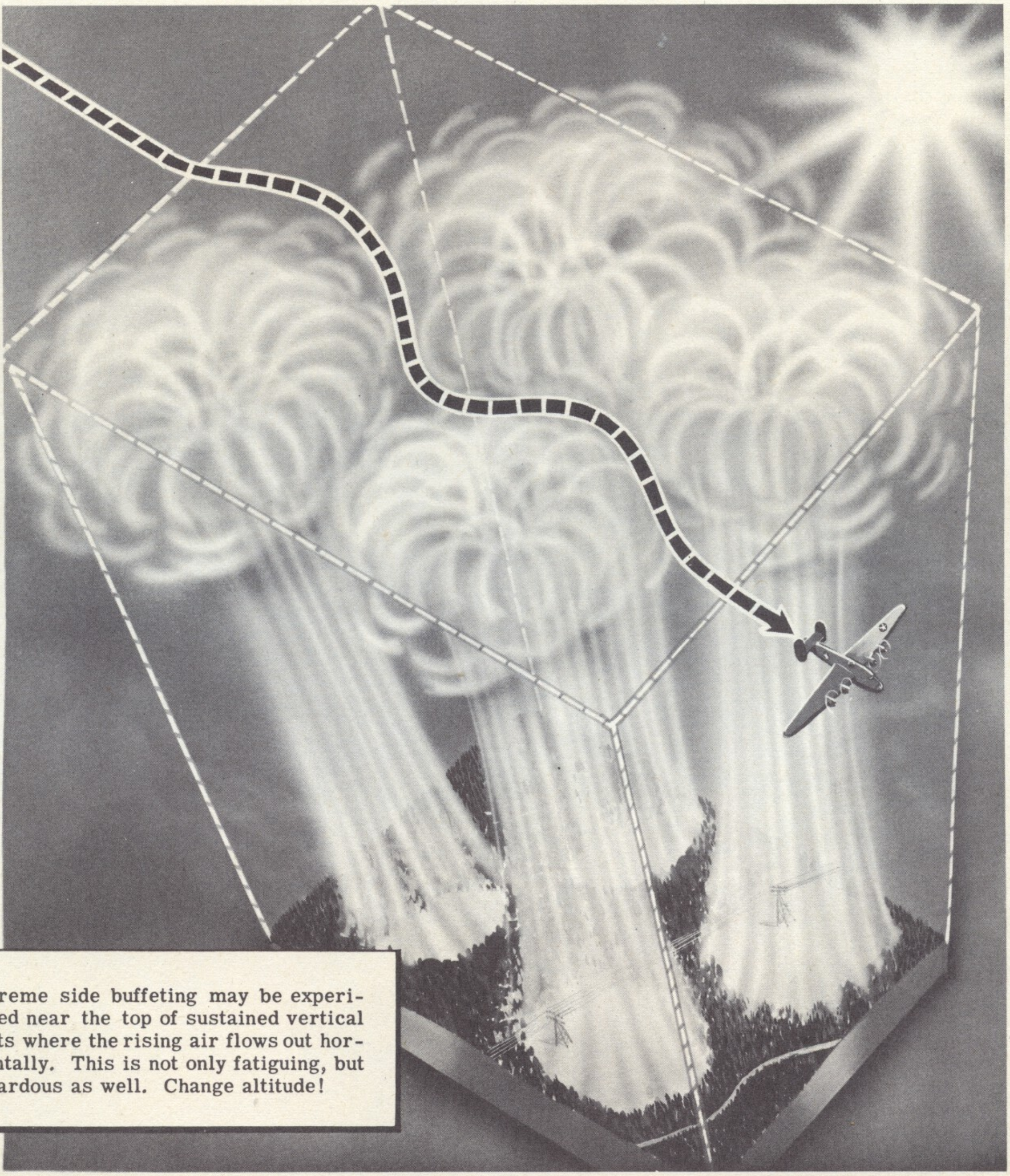
3. Do not worry about your altitude too much if you are safely above obstructions. Maintain air speed first, altitude second.

4. Try to foresee where the air will be rough and at what altitudes. Avoid such regions by flying around them or by definite changes in altitude.



Momentary variations in altitude within reasonable limits should be accepted and the airplane permitted to "ride out" the variable air currents, but maintaining proper air speed and lateral stability.

5. Never exceed twice the stalling speed. The faster you go, the harder a gust will hit you. A strong gust encountered at high speed may result in structural failure. If the airplane is flying at moderate speed, it



Extreme side buffeting may be experienced near the top of sustained vertical gusts where the rising air flows out horizontally. This is not only fatiguing, but hazardous as well. Change altitude!

will stall momentarily before damage is done. Caution is especially necessary if the airplane is overloaded.

WHY WE BUMP

In order to foresee where turbulence will occur, a pilot must understand its causes.

Choppy or bumpy air is produced by the friction of a strong wind over the ground, by the stirring of air which results from strong heating at the ground, or by the interference between two air streams moving in different directions.

When the bumpiness is due to friction, it will not extend far above the ground. It is evident that its upper limit will be higher if the wind is strong or the terrain is rough, but this limit seldom exceeds 2,000 feet. When the choppiness is due to heating, it will start close to the ground in the morning and build upward during the day. Under extreme conditions, such as prevail over a desert in summer, it may extend more than 10,000 feet above the ground. When caused by interfering air streams, the choppy air will be found at whatever altitude the boundary between the air streams lies.

Do not try to avoid turbulence by flying close to the ground at reduced speed. If you reduce speed to minimize the effects of turbulence, you should maintain plenty of altitude. Remember that if you slow down by lowering the landing gear or reducing engine rpm, power to make a quick recovery from a stall may not be instantly available.

If each rising gust of air could be seen on a hot day, it would look something like a large bubble of oil rising through water. When these rising bubbles reach a level where the air is stable and they cannot rise farther, they must spread out sidewise. These cause gusts which may buffet an airplane from one side to another. Since the pilot must watch the instruments carefully in turbulence, he may experience intense muscular and eye fatigue in his continuous effort to retain the attitude of the airplane. This condition can usually be avoided by a change in altitude, since the stable air higher up will be smooth.

The zone of turbulence produced by interfering winds along a frontal surface is also of limited thickness. However, since such surfaces are usually sloping, a minor change in altitude will not always clear the zone. If you don't find smoother air by going up, try going down. Sometimes this means losing a favorable wind, but it should be remembered that even moderately choppy air will reduce ground speed by 5 to 10 percent.

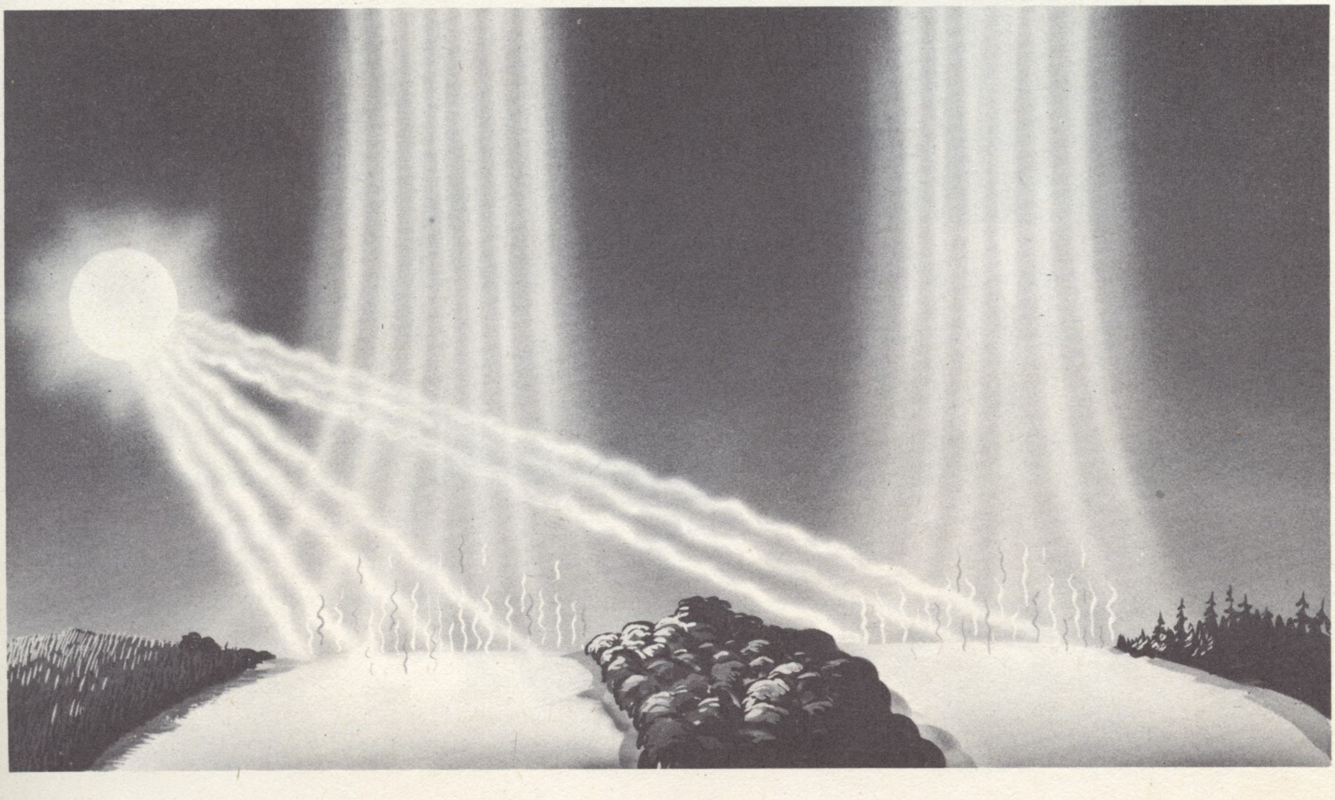
CAUSE AND EFFECT OF DRAFTS

Turbulence in the form of drafts will usually come from:

1. Strong heating of the air at the ground. When wind is light, the rising currents are likely to be well separated and quite large in size; with a stronger wind, choppy air usually results.

2. The heating of rising air by the condensation of moisture. In this case, the drafts will always be within cumuliform clouds.

Sustained drafts are most frequently found over barren areas, such as plowed fields, beaches, cities, etc., that serve as ideal heating surfaces, drawing cooler air from the surrounding vegetation-covered ground.



Sustained vertical air motion produced by an abrupt change in the slope of terrain has many of the characteristics of a draft, but the vertical velocity and height of penetration is determined by the stability of the air, wind velocity, and slope and height of the obstacle.

3. Vertical deflection of a horizontal current of air against an abrupt mountain barrier or other obstacle.

Since the individual gusts thus produced are much larger than those in choppy air, they are likewise farther apart. However, they persist for a longer period and their velocity is often greater. Hazards presented by this type of turbulence are:

1. Possibility of structural failure.

2. Possibility of stall caused by sudden change in angle of attack.

3. Loss of control if the pilot is not prepared for sudden change in flight path.

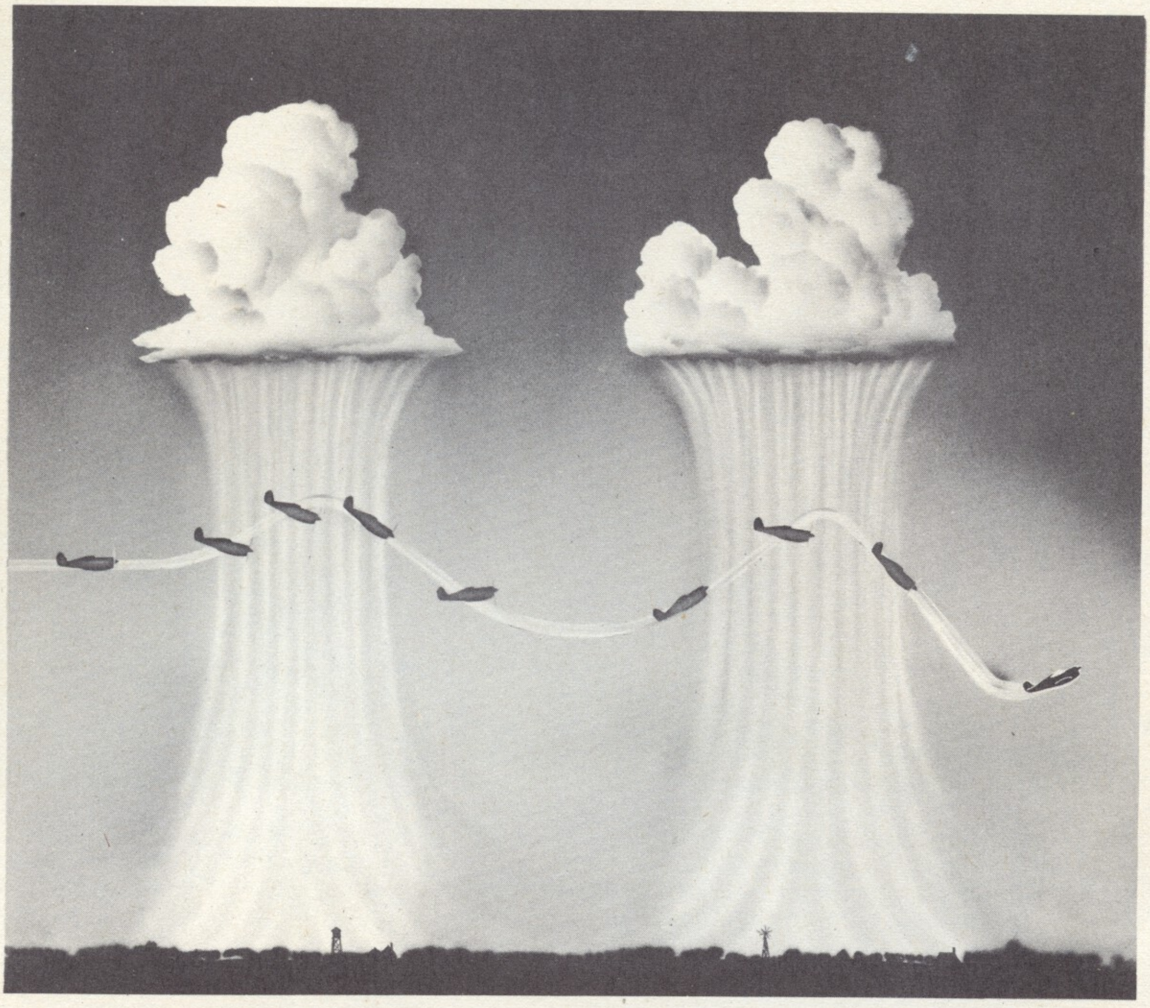
Since a vertical gust will usually have definite boundaries, the angle of attack of an airplane entering a rising current will be increased suddenly and the plane will rise. Normal pilot reaction is to nose down; but if at the same time the airplane comes out at the other side of the ascending current, it will be forced into a dive. If recovery is attempted at the moment of entering the second updraft, the nose-up attitude of the plane combined with the sudden increase of load factor can produce a stall.

GIVE THE AIRPLANE A CHANCE

In areas of sustained vertical currents it is good flying practice to ride out the turbulence with a minimum of control. Every effort should be made to let the airplane fly itself. The control should be used only to prevent excessive changes of air speed or attitude.

Reduction of air speed to 50 percent above stalling speed is sound practice when drafts are encountered. This greatly reduces the chance of excessive strain being placed on the aircraft's structure and makes it easier for the pilot to correct gradually for variations in attitude. In some cases only one wing will be affected by a rising current, with the other wing remaining in still air. Overcontrol under such circumstances can produce a spin.

There is always an upper limit to vertical currents. This upper limit may be indicated as the top of cumuliform clouds; but if the air is very dry, there may be drafts without any clouds, or there may be downdrafts which produce no clouds at all. In moist air masses, clouds will generally show where the vertical currents are.



Overcontrol in an effort to maintain constant altitude in a series of sustained drafts may produce a stall or dive.

SAFER AND EASIER TO STAY ABOVE

On long flights it is good policy to fly above the tops of cumulus clouds or, if they extend too high, to fly at least above the level of the cloud base, around individual cloud masses. Flight beneath the clouds is likely to be uncomfortable and tiring, and in the worst cases adequate control requires constant vigilance.

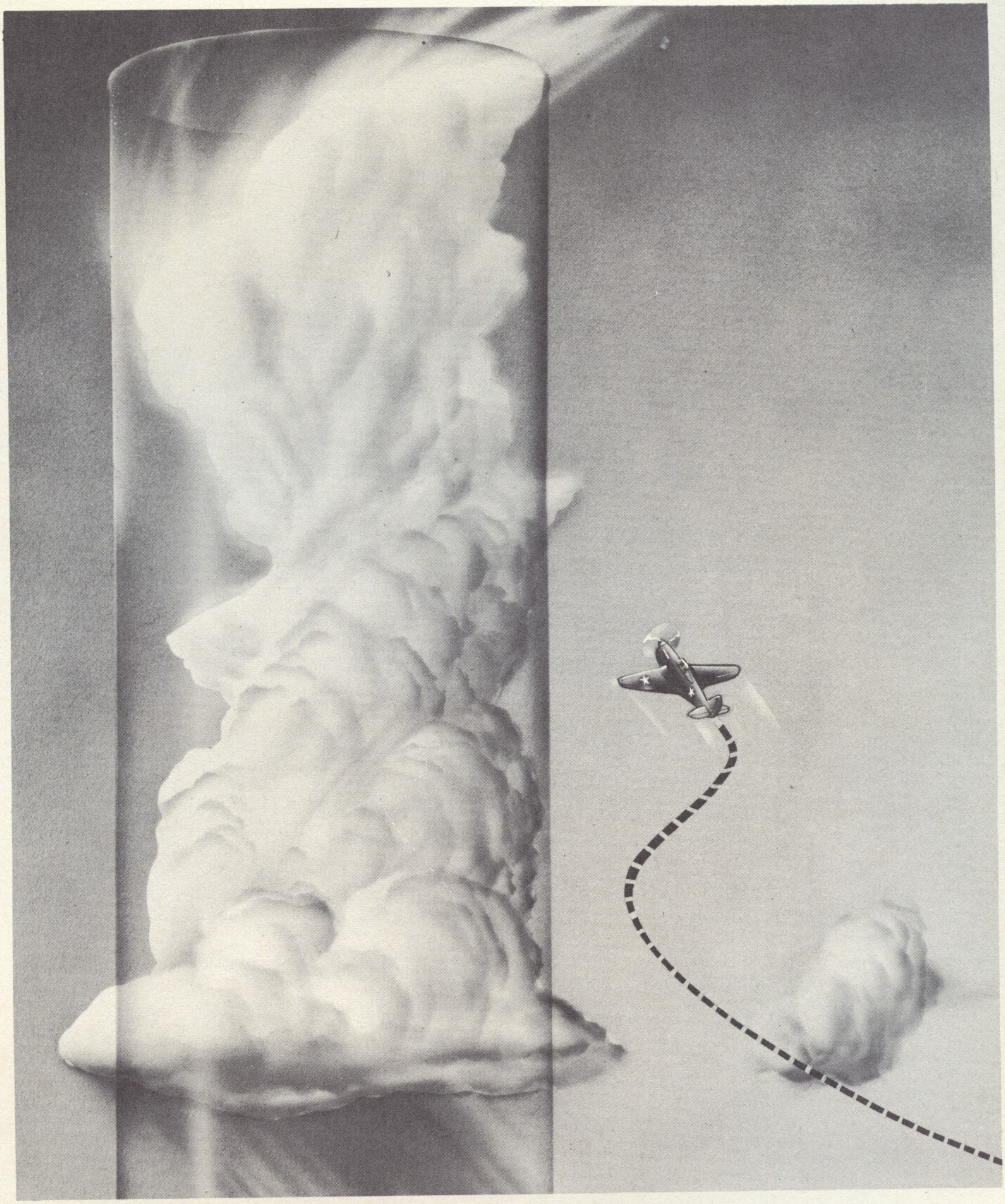
The turbulence associated with thunderstorms and squalls is usually a combination of choppiness and drafts. Large up or downdrafts occur, and in addition, the air may be extremely bumpy within the draft. The procedure to be followed in flying in the vicinity of squalls and thunderstorms will be treated in sections VI and VII.

Descending drafts are not as frequent and rarely as violent as ascending drafts. However, serious downdrafts can and do occur, particularly in the vicinity of local showers. In a shower of cold rain or hail, the relative density of the air will be increased by the evaporational cooling, and the air dragged downward by the weight of falling water. The downward velocity frequently increases as the air nears the ground.

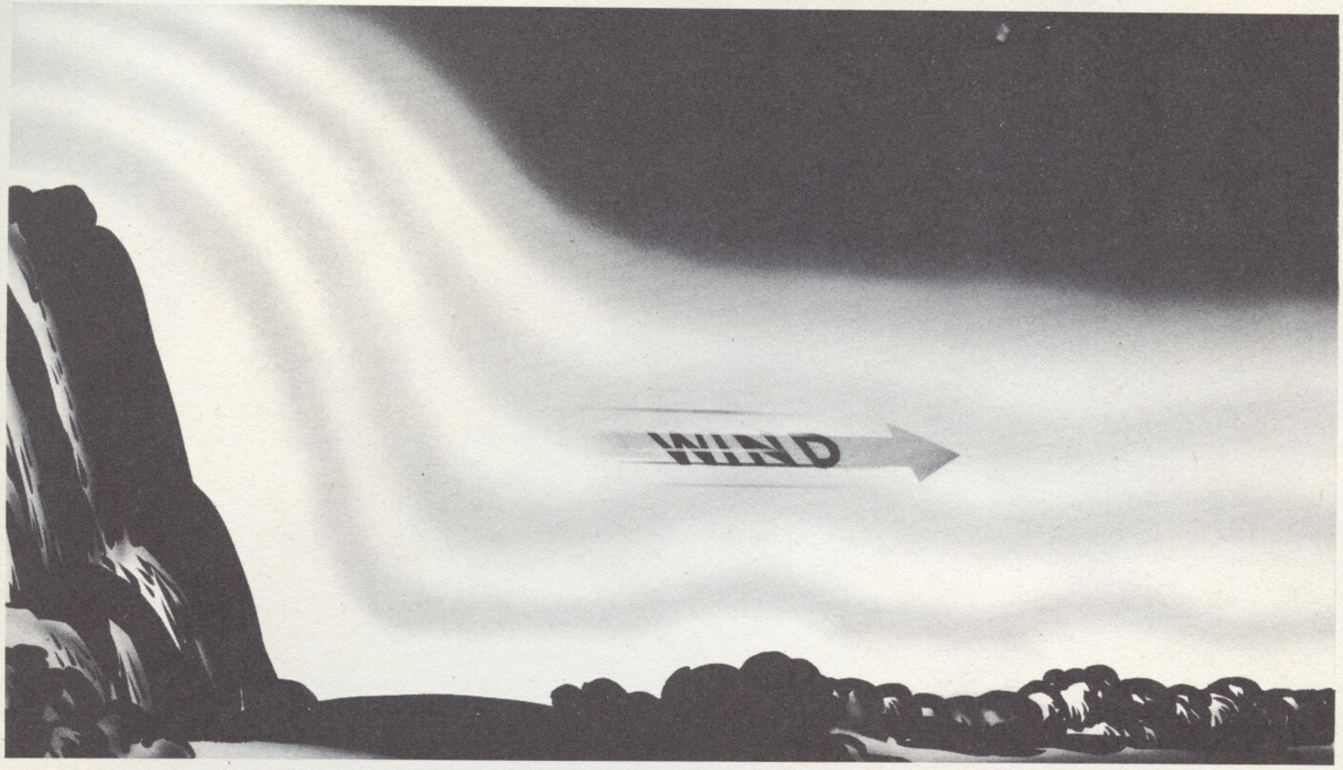
Passing through scattered rain showers, particularly on a hot day, the pilot should expect such downdrafts. If he encounters one at a low altitude, he should increase speed and hold his heading, while anticipating the bump when he reaches the far edge of the downdraft. At high altitudes, it is generally possible to ride out the downdraft while maintaining a level flight attitude.

LITTLE ONES ARE THE WORST

When half the air is rising and the other half sinking, neither current is likely to move very fast. But when the air is sinking over approximately 9/10 of the area, and rising over 1/10, the rising air must move 10 times as fast as the sinking air. You can see from this that it is not the large areas of gen-



Regions of turbulence should be anticipated and avoided by circumnavigation. Cumulus clouds are examples of the columnar form of sustained drafts.



Downdrafts on the lee side of hills are most severe near the surface.
Maintain adequate altitude, even though the wind may be stronger.

eral rainfall that will indicate the worst turbulence, but the small, violent areas of shower or squall.

Never dive an airplane to avoid turbulence. Such a maneuver may result in stress far in excess of the design limit of the aircraft. Moreover, if a downdraft is encountered, you may recover from the dive only with difficulty and a great loss of altitude.

Without question, the pilot's primary effort when in turbulent air should be to maintain approximately constant air speed at all times, and to avoid any maneuver which might produce a stall or spin. This can be done by holding a constant heading, guarding against overcontrol, and maintaining an indicated air speed about 50 percent above stalling speed. The experienced pilot will avoid regions of moderate and severe turbulence whenever possible. He does not subject himself or his airplane to needless strains, nor his mission to unnecessary hazards.

Section IV

ICE ACCRETION

The less experience a pilot has had with icing conditions and the less he knows about ice accretion, the more likely he is to find it a hazard.

The added weight of ice is not its principal danger to aircraft. The principal danger is reduction of the airplane's aerodynamic efficiency. This comes about in three ways:

1. Decreased propeller efficiency.
2. Diminished lift, due to deformation of the airfoil and resulting turbulence.
3. Increased drag, due to deformation of the airfoil and resulting turbulence.

These three factors work together. Increased drag and decreased propeller efficiency mean that a great deal more power is needed to maintain a safe air speed. Deformation of the airfoil means that stalling speed is increased so that a much higher minimum air speed must be maintained. Airplanes with high wing loading or critical control characteristics are quickly rendered unflyable by even a small accumulation of rough ice. It is essential for the pilot to know the characteristics of his airplane before attempting to fly in an icing condition.

Another important consideration is that icing soon limits the pilot's choice of maneuver. With reduction of maximum air speed, the ceiling of the aircraft is also rapidly reduced and the danger of loss of control is proportionately increased. In this way the pilot may have no choice but to descend to a lower altitude. Over mountainous terrain or when the ceiling is low this is obviously hazardous.

NO NEED FOR SURPRISE

Except in the form of frost, ice accretion occurs only in rain or in clouds where there are water droplets at a temperature below freezing. Therefore, a pilot need never encounter icing conditions unexpectedly. Prior to his flight he should consult his forecaster or the adiabatic charts and forecasts for his route. Regions of probable icing are forecast with ease. In addition, his air thermometer indicates the temperature at his flight level, and clouds or rain will reveal the presence of water in the liquid state.

Because water on the wing may be cooled by evaporation it is possible for light icing to occur when the air temperature is slightly above freezing. It is good flying practice to look for ice formation whenever the air temperature is 2°C or lower and clouds are present.

Types of ice adhering to an airplane may be classified by appearance, structure, and location of the formation. The three basic types are:

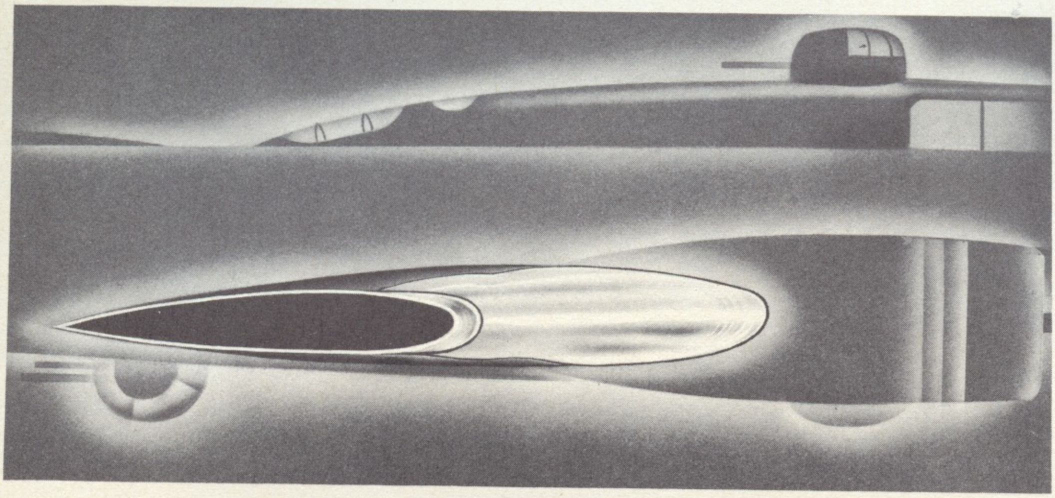
GLAZE LIKELY TO MAKE TROUBLE

1. GLAZE. (Clear Ice)

A glassy transparent or whitish form of ice that adheres tenaciously to exposed surfaces. Glaze accumulates most heavily on the leading edges of propeller blades, airfoils, or forward facing surfaces, often forming in successive smooth, strong layers. It is difficult to remove except by breaking the seal between it and the underlying surface, or by melting. Glaze is formed when water accumulates faster than it freezes, by collision with raindrops or cloud droplets, so that the outer surface is always wet with an excess of free water.

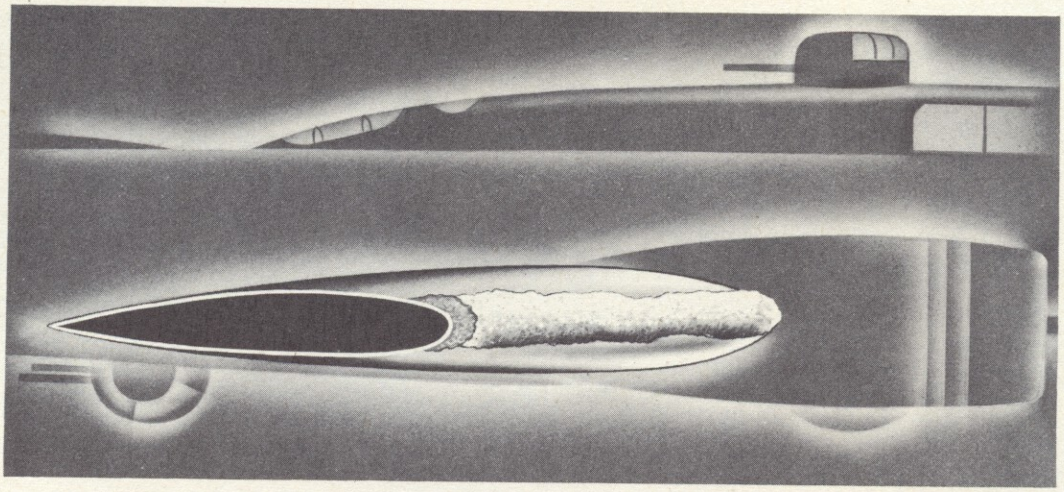
Glaze generally conforms to the shape of the structure to which it freezes and, therefore, is slow to distort the form of the leading edge of a wing. However, the excess of free water will flow back over the top or bottom of the wing and part of it will freeze there, roughening the wing surface. This roughening greatly increases drag and also increases the stalling speed.

Because the accumulation of glaze over the deicer boot itself does not greatly affect the efficiency of the wing, a question arises about the use of the deicers. Many experienced pilots do not favor their use in glazing conditions. A ridge of ice left along the rear edges of the boot may only make matters worse. Also, the removal of ice from one wing while ice re-

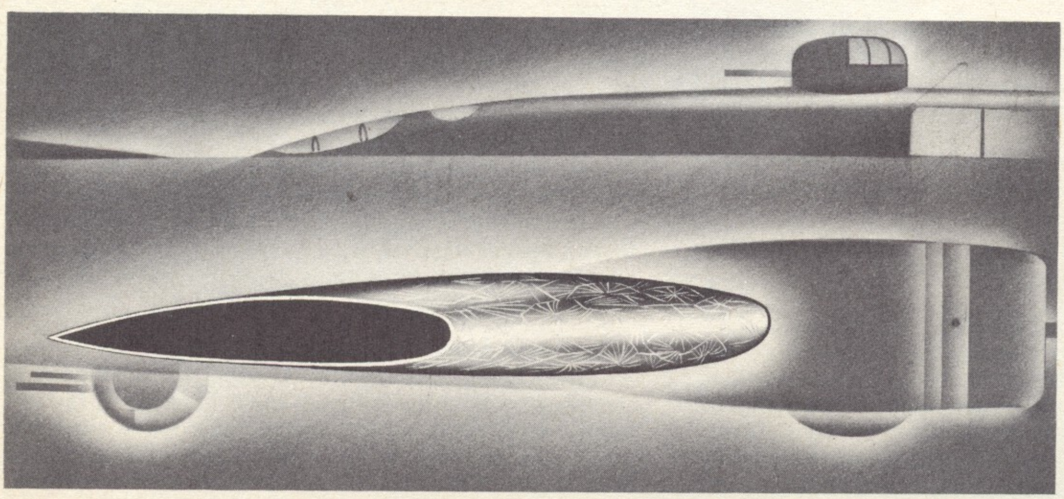


If permitted to accumulate, the glaze will conform to the contour of the airfoil, providing level flight is maintained. A change in attitude or improper de-icer removal will produce humps and ridges.

Rime produces an uneven rough ice accumulation that does not conform to the airfoil contour.



Frost has no appreciable thickness or weight, but reduces lift and air speed by disrupting flow within the boundary layer.



mains on the other wing can reduce the air speed and decrease the controllability of the airplane. Proper procedure must take into account the type of airplane and the expected duration and intensity of the icing condition for the particular flight.

Centrifugal force will ordinarily keep the propeller blades free of clear ice. Near the hub, where centrifugal force is less, an accumulation of ice may develop, causing vibration. However, serious power loss is seldom experienced as a result of clear ice on the propellers.

RIME MAY BE NO JOKE

2. RIME.

Porous, white, usually granular or feathery in appearance, and not as dense as glaze. Rime forms when water droplets freeze as fast as they accumulate. Since this freezing is almost instantaneous on striking the airplane, there is no excess of liquid water. Hence rime forms only where the droplets hit. This will be principally on leading edges, but rivet heads and other minor protuberances may also accumulate rime. Because rime lacks the mechanical strength of glaze and because it does not spread back from the de-icer boot, it is more easily removed than glaze. Since rime freezes rapidly, it may adhere to the propeller blades, but centrifugal force will usually dislodge it and maintain propeller efficiency. However, the rime may not break simultaneously from all the blades. This unbalances the propeller, causing severe vibration and necessitating a reduction in rpm. Until balance is again established by removal of ice from the other blades, the available power is seriously diminished.

Occasionally a very light accumulation of rime may form a narrow, sharp-edged bead of ice along the leading edge of the wing. Such an accumulation appears to be too slight to be of any consequence; but if the air speed is reduced, as in a landing approach, the angle of attack changes and the tiny bead may then have a profound effect upon the stalling speed. The only safe rule is to maintain an excess of air speed whenever there is any ice whatsoever upon the wings.

On structures not protected by de-icers, rime will sometimes form in extreme and unusual patterns. Reports are on record of such peculiar formations as a tapered cone built forward from a loop antenna for a distance of 14 to 16 inches, and an 8- to 10-inch projection from the air-speed pitot head supported at the base on an area of less than 1/2 square inch. Icicle-like formations appear on antenna wires, individual spikes being 6 to 8 inches long. Such formations greatly increase the drag and correspondingly cut down the air speed.

Formation of rime is favored by low temperature, small cloud droplets, and a small over-all quantity of liquid water in a given volume of cloud. However, the accumulation of rime can be very rapid if the temperature is low and the number of droplets great.

FROST

3. FROST.

Individual crystals of ice adhering to the skin of the airplane. Frost forms when a cold aircraft moves through air which is relatively warm and moist or when it passes through air which is supersaturated with water vapor. It forms not only on leading edges, but on all surfaces exposed to the air. Although the total weight of the accumulation is negligible, the great number of individual crystalling spikes of ice produces serious drag and tends to disrupt air flow in the boundary layer next to the airfoil. This may be sufficient to increase stalling speed very unexpectedly.

Frost formation seldom occurs in middle latitudes. In the Arctic, however, it is encountered often, particularly during periods of extreme cold. Although it occurs most frequently at low altitudes it can also occur at higher altitudes, particularly in the lee of mountain passes, or wherever the normal flow of wind is restricted.

Frost forms when the air next to the airplane's skin becomes supersaturated with water vapor. The vapor then turns to ice without passing through the liquid state. Frost can, therefore, form in clear air and its formation cannot always be foreseen. Pilots operating in the polar region must know the peculiarities of this type of icing and take proper precautions.

Of course, a heavy accumulation of frost may gather on the wings of an airplane parked in the open overnight. When this happens, take-off should never be attempted until all frost is removed from the wings. There have been many instances of airplanes carrying only a light accumulation of frost which were unable to leave the ground.

MIXED FORMS OF ICE

Not all the ice encountered will be either glaze or typical rime. As conditions vary between those forming glaze and those producing rime, any intermediate form of ice may result. If snow is encountered together with glazing conditions, snowflakes may adhere and freeze to leading edges, producing a thick, rough accumulation in a short time. It is even possible that very wet sticky snow may pack on the leading edges, producing accumulation not unlike ice in its effect. However, dry snow or ice crystals will not adhere to an aircraft, so that an ice cloud or a fall of dry snow does not present any icing hazard.

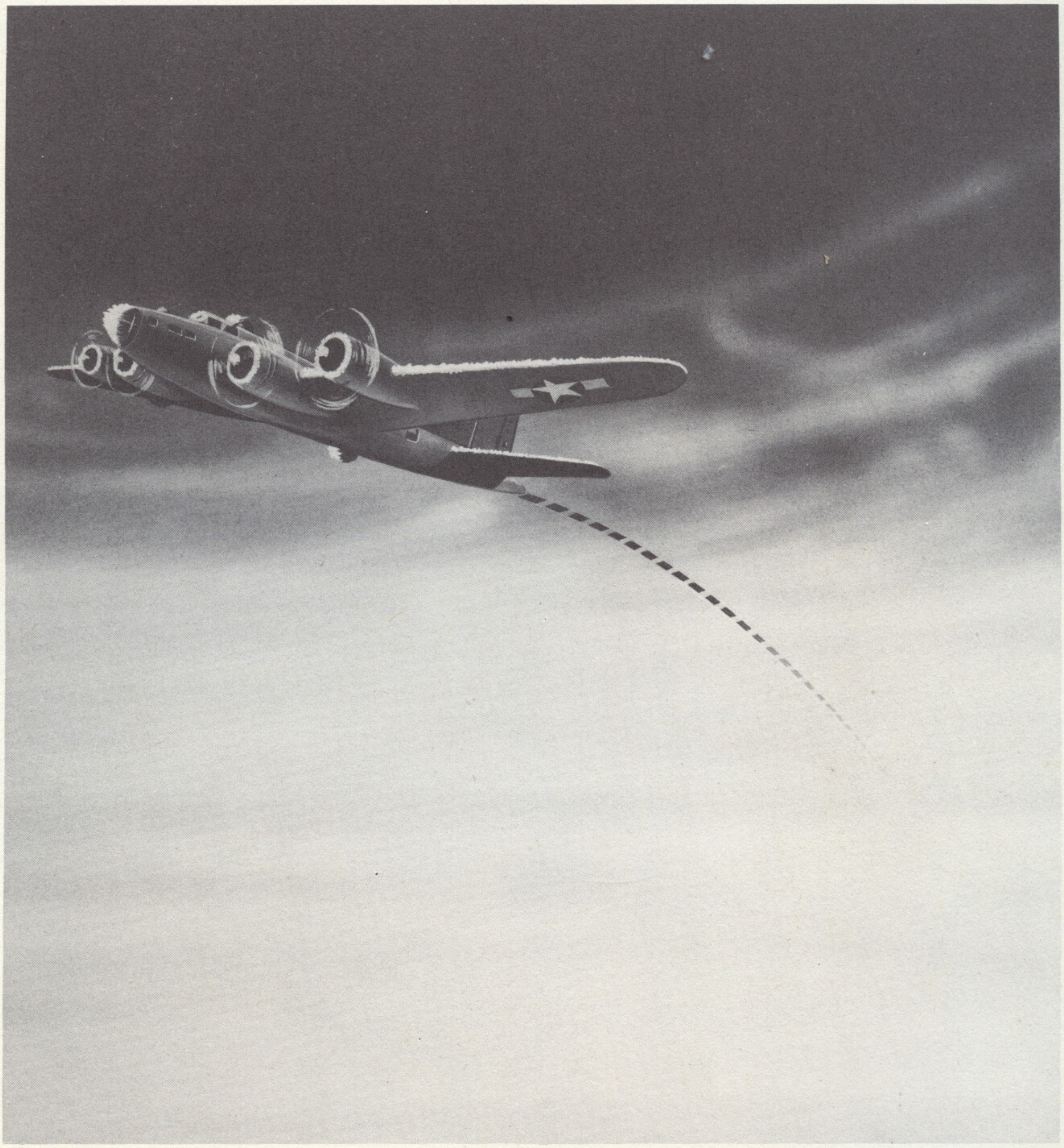
WHERE TO EXPECT ICING

Since the rate at which ice accumulates can be no greater than the rate at which liquid water is deposited on the airplane, regions of greatest icing hazard in the air are the regions where there is the most liquid water at freezing temperatures. The most liquid water will be present when air starts out warm and moist but is cooled rapidly by expansion upon rising to a higher altitude. Regions where rapid lifting occurs are to be expected in the neighborhood of fronts and within cumulonimbus or large cumulus clouds.

Glaze occurs most frequently in clouds of high density, that is, composed of numerous large, water particles. Glaze also forms in freezing rain and freezing drizzle.

When the air, before lifting, was initially quite cold or dry, it could not contain much moisture and any cloud which formed in it could produce only light icing. At temperatures below -20°C, the possibility of serious icing is, therefore, small in any except cumulonimbus clouds. Within cumulonimbus, however, the accumulation of ice at a low temperature may be extremely rapid. In this case, the windshield will rapidly be coated with ice and the view through it obscured. The appearance of the windshield should never be taken as an indication of the thickness of ice on the plane. The pilot should always judge the degree of icing by observing the formation on the airfoil surfaces.

In summer the freezing level will be, on the average, higher than in winter, so most icing will occur



Rime most frequently occurs in clouds of low density, that is, composed of small water particles relatively well dispersed. Rime usually forms with temperatures lower than those favorable for glaze.

in the tops of cumulus of cumulonimbus clouds, usually in squalls, showers, or thunderstorms. In winter, icing may be encountered at any altitude in similar conditions.

When the temperature is below freezing at the flight level, cumulus or cumulonimbus clouds should be avoided. The hazard of ice accretion within them is likely to be greatly accentuated by turbulence.

ICING AT HIGH LEVELS

In a warm tropical air mass, or on the warm air side of a front involving such an air mass, icing conditions prevail only at high levels because the temperature at low levels is above freezing at all seasons of the year. Therefore, in tropical air, icing may be avoided by flying at a medium or low altitude. When a front is approached from a warm air mass, the best plan is to fly where the temperature is just above freezing until the front is encountered, then hold altitude if icing is not severe or climb to find an altitude free of icing.

When the air mass on a warm side of a front is strongly modified tropical air, or transitional polar air, severe icing conditions must be expected and they will extend to relatively low levels. Such air is likely to be unstable, so that the lifting of the air along a front produces convective clouds in which a large quantity of liquid moisture will be suspended.

Along cold fronts icing conditions will vary with the type of weather associated with such fronts. If the cold front is displacing a moist, hot air mass, the icing conditions will be similar to those occurring in thunderstorms. If, however, the displaced air mass is conditionally unstable with a low freezing level, the icing conditions may be severe and the horizontal extent of the icing may equal or exceed that associated with warm fronts.

STABLE AIR - RIME

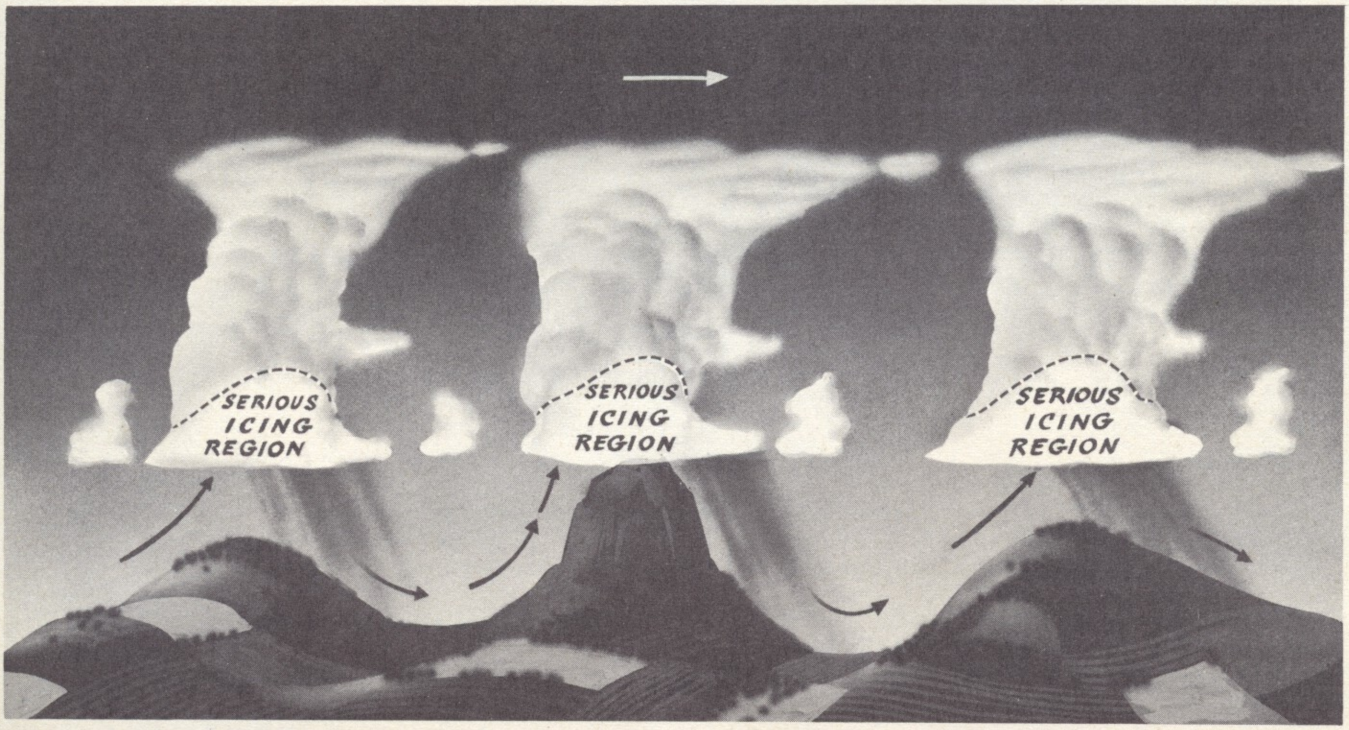
Clouds characteristic of stable air, that is, stratus types and extensive cloud sheets having rather level bases and tops, usually produce only rime. However, thick sheets of stratocumulus clouds may contain sufficient liquid water in their upper portions to produce glaze.

Where there is an unstable layer of cloudy air surmounted by a marked inversion, icing is generally most intense in the top of the cloud layer. Flight can often be maintained through the middle or lower portion of the layer without encountering more than light icing; yet an attempt to climb on top may result in an accretion so rapid that the plane will be unable to gain further altitude.

The intensity of an icing condition may increase rapidly if an initially stable air mass becomes unstable. For this reason a pilot should never unquestioningly rely on reports even a few minutes old, from flights passing through the same region ahead of him.

EVALUATING ICING INFORMATION

No satisfactory terms have yet been found for describing the degrees of intensity of ice accretion. Many variable factors, some of them not well understood, influence the effect of ice. A slight change in air speed or angle of attack may suddenly change the flying characteristics of an airplane carrying ice. One type of plane may find serious icing conditions where other types fly safely. These circumstances must be considered in evaluating reports. It must never be taken for granted that any icing condition will remain unchanged, and all reports should be studied with the

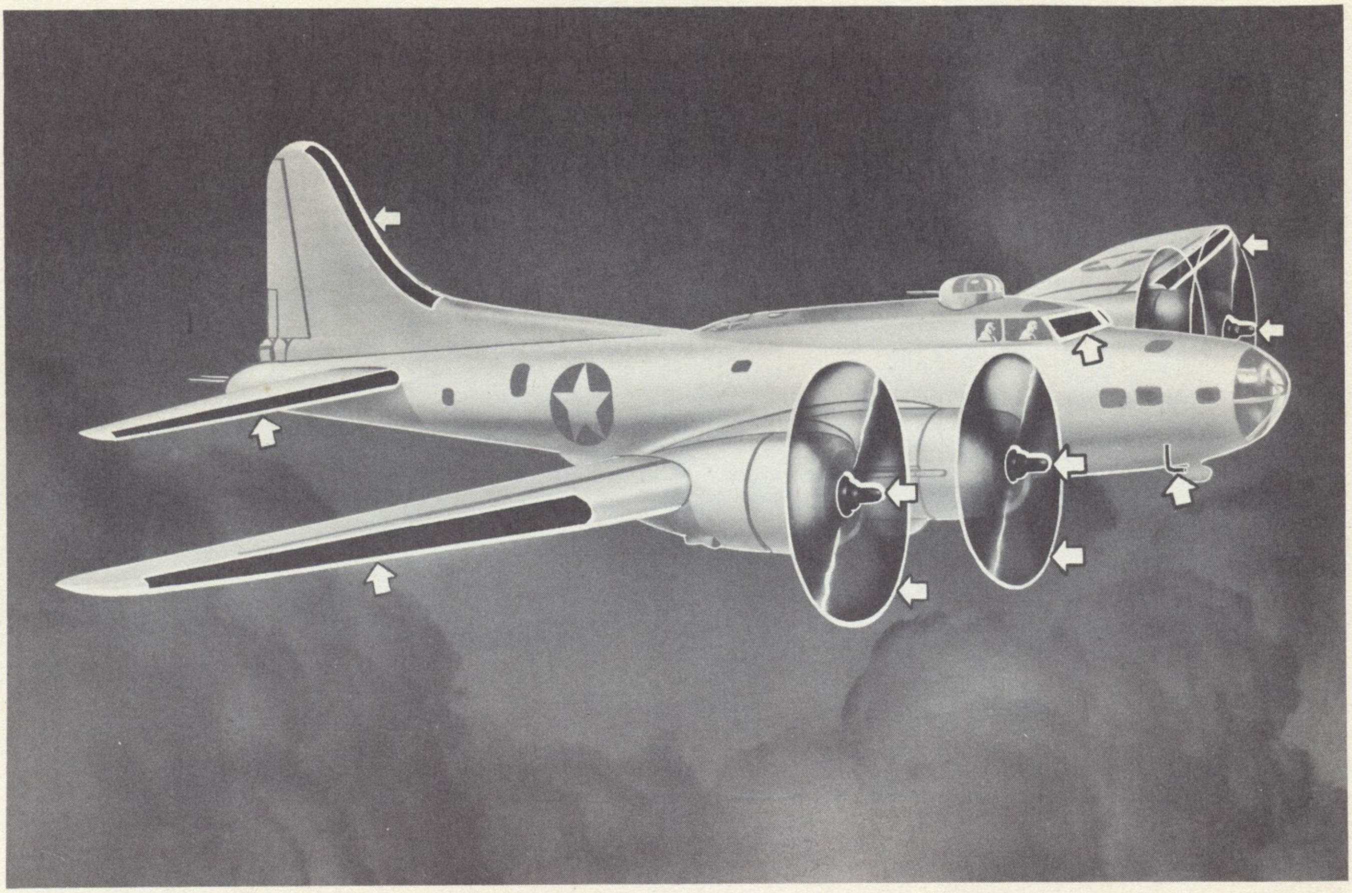


The combined effects of terrain and instability of the air mass produces serious icing conditions in the bases of squalls and showers along ridges and mountains. These regions should be avoided by circumnavigation, or topped.

help of a forecaster. Blind acceptance of reports an hour or more old may lead to a pilot being cleared into an intensifying icing condition, or to delay unnecessarily when, in fact, the condition is diminishing.

Local variations in the use of icing terms must be kept in mind when talking with pilots and forecasters in other portions of the globe. For instance, British and Canadian forecasters speak of ice which cannot be removed by de-icing equipment as clear ice, regardless of its appearance; and of removable ice as rime.

Rain alone seldom results in a serious icing hazard. The temperature is rarely much below freezing, and the ship's speed tends to sweep off the raindrops before they can freeze. Also, the region in which freezing rain occurs will generally not be large.



It is just as important for the pilot to know the characteristics and functions of de-icer equipment, as to know the limits of his airplane and engines.

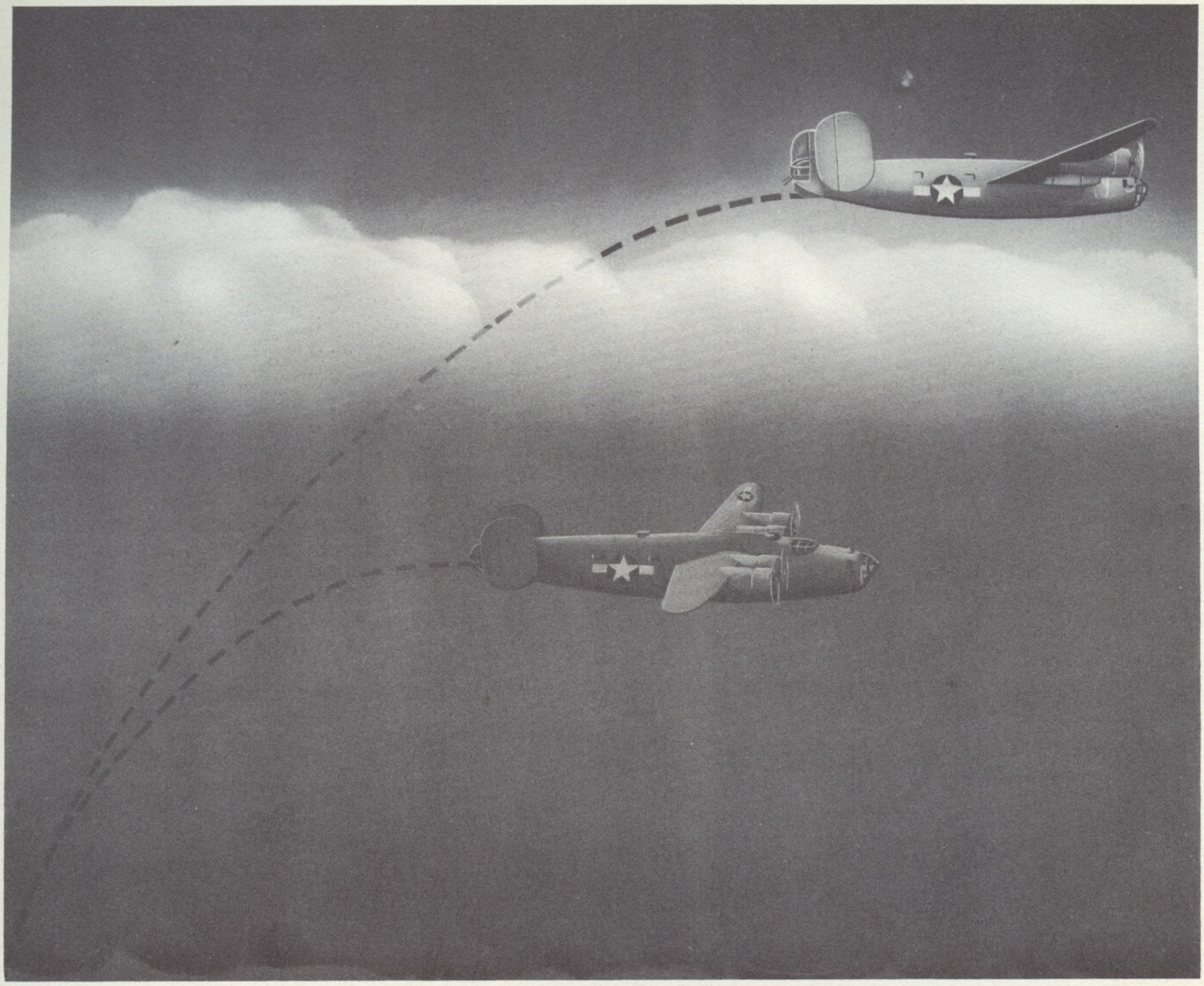
WHAT TO AVOID IN FLIGHT

Great care should be exercised in attempting to fly through any known icing condition. Even light icing should be avoided unless the airplane is fully equipped with de-icers, including boots, propeller anti-icers, and carburetor de-icing equipment, or else the hazard of observation and attack by the enemy exceeds the hazard of icing. The air temperature gage should be a pilot's constant guide, but an allowance of as much as 5 degrees must be made for possible inaccuracy of the instrument.

Even with full de-icing equipment, flight through icing regions should be undertaken only for the purpose of reaching a safer flying level free from icing hazard. Safe flying levels can usually be determined in advance with the aid of a forecaster or adiabatic charts. De-icers were developed as a safety device in case of trouble, and they cannot replace common sense. If, for military purposes, extended flight through an icing condition is undertaken, the pilot must be fully acquainted with the effect of de-icers on the control characteristics of his airplane during level flight, maneuvers, and landing. He must know to what extent the stalling speed or other flight characteristics are altered by inflation and deflation of the de-icer boots. Inflation of the boots may cause stalling at speeds the pilot is accustomed to consider safe. THEREFORE, DE-ICERS MUST NEVER BE LEFT OPERATING WHEN LANDING OR TAKING OFF.

WHEN TO USE DE-ICERS

Efficient performance by de-icing equipment de-



De-icing equipment should be used to enable the airplane to safely reach ice-free levels, and not to maintain flight in icing conditions. Do not overwork them, particularly propeller and windshield de-icers, thereby exhausting the supply of anti-icer fluid.

pends upon its correct use. Whenever possible, the propeller, windshield, and pitot head de-icers should always be placed in operation before the pilot enters the icing region. Many pilots have individual preferences regarding the use of de-icer boots. A satisfactory practice is to permit the deposit of about 1/8 inch of ice on the boot before inflation is started, to break this deposit clear, then to operate the de-icers intermittently as new deposits form. Some experienced pilots prefer not to use de-icers at all in glazing conditions. If the boots are operated continuously, a new sheet of ice may form over the cracked ice on the boots, and the tubes will pulsate ineffectively beneath a flexible sheath of ice. Under some conditions, however, ice formation is extremely rapid and continuous operation of the boots may be necessary.

Ice may sometimes be removed from propeller blades by changing the engine rpm rapidly several times. The practice must be resorted to with caution, however, particularly in using emergency power. Ice on the blades may cause the propeller to stall because of increased loading when emergency power is used. The perilous effect of this, particularly when thrust is needed to extend a landing approach glide, is readily apparent.

Icing of the pitot head will cause the air speed indicator to show a decrease in its readings. This might lead the unobservant pilot into a dive exceeding the load limits of the aircraft with resulting structural damage. This is especially dangerous in rough air with glaze ice. If icing conditions are expected, or whenever water in visible form is encountered, pitot heat should be turned on and left on well in advance of encountering the actual icing situation.

Procedures to be followed in avoiding icing conditions in various types of weather will be treated in section V. Avoid ice. If icing regions cannot be avoided, flight through them should be made as short as possible and should never be attempted unless effective de-icing equipment is available.

CARBURETOR ICE

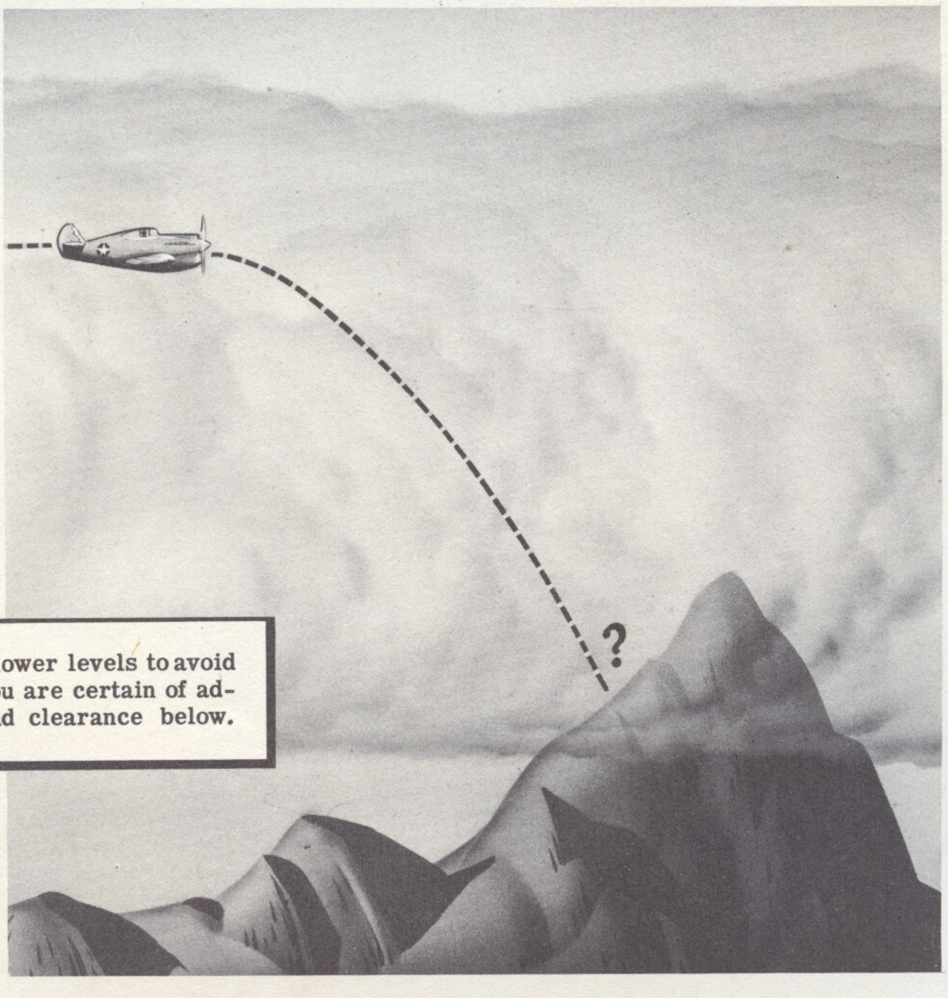
Carburetor ice is not ordinarily classified as a type of ice accretion, but because of widespread unfamiliarity with the subject it will be discussed here briefly.

The prevention and elimination of carburetor ice is an engineering problem. It has been solved by the engineers. Procedures and methods to counteract carburetor ice have been developed to suit particular engines and carburetors.

Carburetor ice is due to the refrigeration occurring in the induction system of the engine. Ice usually forms in the supercharger adapter or on the butterfly-type of throttle valve and will eventually close off the air passage. Since the fuel flow is not interrupted, the formation of ice in the carburetor venturi will be indicated by a rapid increase in the fuel - air ratio, resulting in power loss and eventual stoppage of the engine. The most evident indication of carburetor ice will be a drop in the manifold pressure and, by keeping close watch on the manifold pressure gage, carburetor ice may be eliminated before it becomes too serious. Sometimes application of carburetor heat at intervals will be sufficient, thereby allowing the engine to develop its full power between applications. On certain types of carburetors, ice may form on the nozzle bar or on the nozzles themselves, partially closing the nozzle openings and thus making the mixture leaner. Either type of ice formation is dangerous, and must be eliminated as quickly as possible by the application of carburetor heat or by an alcohol or anilol spray. Either of these procedures will remove the ice by melting.

FREEZING AT 15°C

Cooling of the air in the engine induction system amounts to 10° or 15°C in the average aircraft engine. It is, therefore, possible to have ice form in the adapter when the outside air temperature is as high as 15°C. The refrigeration is the result of the evaporation of the gasoline and the expansion of air through the venturi and behind the throttle. If the cooling is sufficient to produce condensation of water from the inducted air, carburetor ice may form when the plane



Do not seek lower levels to avoid ice unless you are certain of adequate ground clearance below.

is flying through clear air. Cloud particles, if present, will contribute to the process, particularly if their size and number is sufficient to result in a continuous deposit.

Carburetor ice is readily prevented by the application of carburetor heat before the conditions which may produce ice are encountered. The heated air keeps the temperature above freezing throughout the induction system, thus preventing the ice from forming or melting that already formed.

Carburetor ice will not usually form in flight through snow. However, large snowflakes may be partially melted upon first entering the induction system, and later may be frozen on contact with the cold walls of the adapter.

APPLY CARBURETOR HEAT

Application of carburetor heat in sufficient time to prevent carburetor ice is always advisable; but as carburetor ice can form in clear air, judgment must be used in watching the manifold pressure and in applying carburetor heat as soon as a drop in manifold pressure is noted, in preference to running the engine with carburetor heat on at all times. However, if serious carburetor icing is expected in clouds or precipitation, do not hesitate to use carburetor heat as a preventive.

Remember that this heat is supplied by the engine exhaust. When the engine has lost power because of carburetor ice, it may be too late to melt the accumulated ice in the carburetor or induction system. If anilol is available, however, it may be used under these circumstances and in certain types of engines it will have the added advantage of increasing the fuel octane number.

Section V

FLYING CLOUDS AND FOG

A pilot should never fly into any cloud without knowing what weather elements he is likely to encounter and what he will do if they adversely affect normal flight.

Virtually all weather problems that confront a pilot are associated in one way or another with clouds or fog. The obscuring of visibility, horizontal and vertical, is in reality a secondary problem, although on occasion it may complicate other problems.

The production of icing conditions and precipitation is always associated with clouds. Turbulence, while not directly caused by clouds, may be caused by the same physical process which results in the formation of clouds, and there is the added complication that flight must be conducted on instruments in these conditions. A relatively slight accumulation of ice and moderate turbulence can have serious consequences when encountered in the course of instrument flight.

WHAT TO KNOW ABOUT CLOUDS

To a pilot, the international classification of clouds based on their appearance has no practical significance. The pilot is interested in those characteristics of the cloud which might adversely affect the normal conduct of a flight. These characteristics are:

1. The horizontal extent and whether continuous, broken, or scattered.

2. Vertical extent, and whether continuous or in layers; if in layers, whether sloping or level, merging or diverging.

3. Turbulence, whether confined to certain layers or present at all levels.

4. Icing conditions, vertical limits, the type of ice, and rate of accretion.

5. Type and intensity of precipitation.

6. The mean and lowest heights of the lowest cloud layer above the ground.

If a pilot is qualified and has demonstrated his ability to fly on instruments, to orientate himself, and to execute an instrument approach with limited ceiling and visibility, only those weather elements encountered en route, closing of his terminal, or mechanical failure, can produce complications in the conduct of the flight.

Low ceiling and low visibility do not in themselves demand a special flight technique. In the final analysis, the pilot has only to determine whether or not a landing can be made at a terminal. If a landing cannot be made, he must proceed to another field where the ceiling and visibility are adequate. However, a pilot "in the clear" can see weather signs around him that are hidden from the pilot on instruments.

When the ceiling or visibility is or may become low, the pilot must plan for the possible use of an alternate airport. Repeated attempts to land under unfavorable conditions will only consume valuable fuel and increased fatigue, not to mention the possible incentive to take unwarranted chances. It is better to swallow one's pride and proceed to an alternate field after one unsuccessful attempt.

THREE CAUSES OF CLOUDS

Cloud masses of sufficient size and extent to warrant consideration as a flight problem may be formed by any one of three principal processes:

1. Vertical convection.

2. Upslope motion.

3. Cooling by contact with a cold surface.

In flight over the top of cold, front thunderstorms or line squalls, circumnavigate the towering cumulus domes.

There are other processes of cloud formation but they are much less important from the pilot's standpoint.

CLOUDS FORMED BY VERTICAL CONVECTION

The usual cause of vertical convection is heating of the air at the ground. Less usual causes are inflowing winds over a large area and lifting of conditionally unstable air. While heating at the ground will ordinarily result in clouds which build up from a low level, the less usual causes may form convective clouds at intermediate or high levels.

Clouds formed by vertical convection may, therefore, be subdivided as follows:

1. Surface heating (cumulus and cumulonimbus).

2. Instability aloft (altocumulus floccus or castellatus).

The individual rising currents of air which result from instability must be surrounded by air which is sinking. The resulting clouds, therefore, developed individually. This counteraction limits the amount of cloudiness that may develop as a result of vertical convection. The clouds at any one level will rarely cover more than 50 percent of the sky unless, the cloud is moderately large and the observer directly beneath it.

While the sinking motion of the air around cumulus and cumulonimbus clouds is usually slow, an airplane will be obliged to maintain a climbing attitude in order to stay at a given level. The ground speed is thus reduced. If flight is made above the tops of the cumulus clouds, loss of ground speed from this cause will be avoided.

Because of the rapid cooling and condensation of water within a strongly developed cumulus or cumulonimbus, the amount of liquid water suspended in it is greater than in any other type of cloud.

STAY ABOVE OR GO AROUND

Within deep tropical air masses, where high humidity is the rule and the air is conditionally unstable, heavy showers may occasionally fall from cumulus clouds whose tops are not above 8,000 feet. Vertical currents within such clouds may be strong and prolonged. The pilot should avoid these clouds by flying over or around them.

In large cumulus clouds, the temperature within the cloud is higher, level for level, than in the surrounding air. Therefore, the elevation of the freezing level in a cumulus cloud is displaced upward, the average displacement being 500 feet or more. The displacement is greatest in the most active clouds.

This higher temperature within the cloud is of some importance in computing the lowest level at which ice will be encountered in cumulus or cumulonimbus clouds. Particular care must be exercised in cumulus clouds that are developing into squalls or showers, where falling snow may contribute to ice formation in the portion of the cloud just above the freezing level.

Small cumulus clouds are typical of fair weather. Except for some turbulence and possible short periods of icing, they present no hazard to the pilot. They may be flown around with ease, topped at a reasonable altitude, or flown under, as the pilot chooses. His own comfort and the requirements of his mission are the deciding factors.

Cumulus clouds are primarily a daytime type, since they are usually the indirect result of solar heating. The occurrence of such clouds at night over land usually indicates conditions which may lead to widespread local storms. Whenever possible, it is best to stay out of cumulus clouds at night.

Over the oceans, the air during the day is normally warmer than the water; but at night, the water remains warm while the air becomes somewhat cooler. Surface heating of the air is thus most marked at night, and cumulus clouds over water accordingly develop mostly during the hours of darkness. When other conditions are favorable, clouds will form rapidly, and because of the high relative humidity of maritime air, the cloud cover is frequently unbroken and the base of the cloud low. Turbulence within such clouds is generally weak, but there may be local regions of more severe turbulence.

In northern latitudes, where the freezing level is within 2,000 feet of the surface except during the summer months, the likelihood of encountering icing and cumulus clouds must always be remembered. The amount of ice formed in any one cloud may be negligible, but during a prolonged flight the accumulation can reach serious proportions. However, the depth of such cloud formations is usually not great and flight either on top or below the cloud base is both possible and recommended.

The characteristics of towering cumulus and cumulonimbus clouds, which convectively formed, will be described in detail in the following sections.

CLOUDS FORMED BY UPSLOPE MOTION

If air moves up a long slope, its temperature is reduced by expansional cooling and the water vapors within it must eventually condense. The form of the resulting cloud, its vertical thickness, and its horizontal extent will be determined by the steepness and extent of the slope, the speed of the upslope flow, and the stability of the air. Sloping surfaces most important in causing upward flow of air are:

1. Warm fronts.
2. Cold fronts.
3. Sloping terrain.

The most important factor in determining how fast a cloud mass will develop within the upward moving air is the stability of the air. If it is conditionally unstable, deep clouds will develop rapidly soon after the first condensation occurs. The degree of turbulence and the intensity of icing will likewise depend upon the amount of instability. In stable air, the cloud will thicken more gradually.

Consideration must also be given to the fact that wind velocity may be greater aloft than at the ground. When this is the case, the higher air is lifted more rapidly than that below, and clouds usually stratiform, form first at a high level.

UPSLOPE CLOUDS YOU WILL MEET

The principal cloud types formed as a result of upslope motion are:

1. Altostratus.
2. Altocumulus.
3. Stratus and nimbostratus.

Clouds formed by gradual lifting seldom produce noticeable turbulence unless the air is conditionally unstable. At times, particularly along fronts, friction with the underlying surface will produce choppy or bumpy air. Sustained vertical currents are exceptional, and if encountered, are invariably associated with cumuliform clouds.

With up-slope motion, the interior of a thick cloud layer may occasionally be quite turbulent, even though the cloud has no cumulus appearance. Drafts, choppy air, and side buffeting may be experienced at irregular intervals, and if precipitation is encountered, mild downdrafts may occur. Instrument flight under these conditions requires the full attention of the pilot. He should utilize the recommended procedures for flight in turbulence. Probably the element of surprise is the greatest hazard when such turbulence is encountered. The forecaster can help in choosing the best flight levels. If the front slopes upward in the direction of flight, smoother air can usually be found at a lower level; if the slope is downward in the direction of flight, smooth air should be sought by climbing.

YOUNG CLOUDS BEAR WATCHING

Factors in estimating the hazard in up-slope forms of clouds include the age of the cloud mass, the rapidity with which it formed, and the time needed to fly through it.

When a cloud forms rapidly, reaching large size while it is still young, the rapid ascending motion of the air carries along a large amount of free water. When the temperature is below freezing, glaze will usually be encountered. The rate of ice accretion depends on the density of the cloud and the speed of the aircraft.

Old clouds, particularly those moving from a warm to a colder surface, generally lack turbulence. Much of the water initially contained in the clouds is lost as rain, so the hazard of ice accretion is much reduced.

The amount of ice accumulated in flying through clouds naturally depends on how far flight is maintained through them. To reduce the ice hazards, the flight path selected should be the shortest path through the clouds.

At high altitudes, with the temperature below -20° C, almost no ice is found except in well-developed cumulonimbus clouds. In flying through up-slope clouds, the pilot should seek high altitude and low temperatures if the freezing level is close to the ground. However, unless the altitude of the cloud top is known, climbing through an icing condition should not be attempted, particularly if rain or snow is falling.

CLOUDS FORMED BY CONTACT COOLING

Whenever warm moist air moves over a colder ground or water surface, cooling of the air near the surface will eventually bring about condensation of the water vapor in the air, forming clouds. The type of cloud will depend upon the wind velocity, the stability of the air, and the presence or absence of precipitation. Stratus is the most common type of cloud formed by contact cooling. Since warm air over a cold surface is cooled from below, the lowest air becomes heavier, increasing the stability. When the air is cooled below the dew point, condensation occurs and clouds begin to form. Since cooling progresses upward from the surface, stratus clouds are ordinarily low and shallow but they may spread over a wide area.

If the wind is strong, turbulence produced by friction will carry the cooling effect upward to a somewhat higher level. The cloud base will then be relatively sharp and definite and the cloud mass as a whole will tend to become stratocumulus.

Precipitation in the form of rain or snow seldom falls from stratus clouds. Light rime icing may be encountered, but it seldom reaches serious proportions except in continued flight without use of de-icers. Since the cloud is usually shallow, flight can be made above it without difficulty. Flying in or below stratus clouds is not recommended because the cloud base is low and even small hills protrude into it.

EXPECT LIGHT DRIZZLE

Unless the wind is strong the stability of the air suppresses turbulence. In light winds the base of the cloud is soft and hazy. It may be quite irregular in height, frequently varying several hundred feet within a short distance.

Stratus clouds with a light wind seldom produce icing conditions. However, drizzle may occur; and if the temperature is below freezing, glaze will accumulate at a slow rate. Flight should not be prolonged through freezing drizzle or even in the clouds above. In the course of a prolonged flight the accumulation of ice may become heavy enough to prevent the plane from climbing on top. If an instrument approach is made through a stratus layer and freezing drizzle is encountered, icing of the windshield will usually obstruct forward vision. Therefore, whenever a descent is made through a stratus cloud, even though the temperature on top is above freezing, it is wise to have the windshield de-icer operating. If there is none, open the forward window. Do not trust to a side window, or "stick your neck out." The altimeter, air speed, and other instruments cannot then be watched; and they will be needed, particularly if scud clouds are present, until your wheels are on the ground.

FOG AND SMOKE

Conditions that limit visibility to less than 1/2 mile present a serious problem only when a landing must be made or when contact flight must be maintained.

The main causes of low visibility are fog, smoke, and dust. Several other weather elements, such as heavy rain or snow, may also reduce the visibility, but they do not present problems as important as the more extensive and persistent conditions of low visibility brought about by fog.

Fog is not difficult to forecast if good weather reports are available. Forecasting the exact time of formation or dissipation is tricky, however, and when flight operations depend upon the accuracy of a forecast, the advice of an experienced forecaster should be sought.

Fog is formed by the same basic process which forms clouds; namely, cooling of the air until its water vapor condenses. In the case of fog, this cooling must take place next to the ground. The causes of the cooling determines the type of fog, which in turn determines the effect upon flight operations.

THE CAUSES OF FOG

There are two principle causes of cooling which operate near the ground, and hence two main types of fog. Each has its local peculiarities as to terrain, time of formation, and duration. Radiation or ground fog is caused by radiational cooling. Advection fog is caused by the movement of air from a warm to a cold surface. Less common forms of fog are up-slope fog, caused by expansional cooling of air moving upward over sloping terrain, and frontal fog, caused by the mingling of warm and cold air at a front and by evaporation of warm rain.

RADIATION FOG

Radiation fog is formed by contact cooling of the air immediately above ground that is being cooled by radiation. It is, therefore, strictly a night and early morning condition, since only after sunset will the ground radiate heat faster than it is received. Radiation fog will not form when the wind exceeds 6 miles per hour. This type of fog occurs most frequently on clear, relatively calm nights.

Cooling of the air by contact with the ground will be restricted to a shallow layer. Since the cooled air becomes heavier, it will drain into low places and along stream beds. The fog resulting will be shallow. In rough or mountainous terrain it will be restricted to valleys and low areas, but over the plains it may hide the ground over a wide area. Radiation fog seldom forms over snow-covered ground unless the temperature is near freezing.

Most airports are located on low ground, and the flat grass-covered surface favors the formation of ground fog. However, wind movement is also favored by the wide unobstructed space, so that wind tends to slightly delay fog formation. Nevertheless, fog formed in adjacent calm areas can readily drift across the airport. From the air, a pilot may see lights shining brightly through a thin layer of ground fog, and the hazard will pass unnoticed until he levels off for a landing and starts to dip into the top of the fog layer. Forward visibility then drops very suddenly. A pilot should always get a visibility report from the ground whenever there is risk of ground fog.

HOW TO LAND

A safe landing can be made if radiation fog is shallow and somewhat transparent, so that boundary markers, runways, and obstructions can be seen from the air. The procedure to be followed will of course depend upon the pilot's judgment and the type of plane he is flying.

In an emergency, the landing must sometimes then be made on instruments. It is best then to "fly" the airplane on to the ground instead of attempting a "stall" landing. The control column should be pushed forward as soon as the wheels touch to keep the airplane from bouncing or porpoising.

When making a landing with restricted visibility, never look for the ground from the side window. While attention is distracted, the air speed may temporarily be forgotten or the left wing unconsciously lowered, resulting in a stall or ground loop. If a second pilot is available, he should call out the altitude and air speed as the ground is approached. This permits the first pilot to give his undivided attention to holding the plane on an even keel and watching for obstacles and runway markers.

Down wind from large cities' smoke will contribute toward lowering the visibility before fog forms. Usually the smoke becomes dense within a few hours after sunset, hanging as a pall at a height of 50 feet or more. When the sky is clear and relative humidity high, water vapor will condense on the smoke particles before the spread between temperature and the dew point is entirely gone, and the visibility will gradually lower. The resulting smoky fog, popularly called "smog," gradually settles to the ground as dew if the air is perfectly calm. The visibility may then temporarily increase before the formation of true radiation fog proceeds.

The increase in visibility after midnight, when a smoke condition has prevailed, should not be taken as indicating an improving trend. If the wind velocity is low and the dew point high, fog is almost certain to follow. If the dew point is lower fog may not form, but the visibility will not improve until after daylight.

On cloudless mornings when smoke is present, the sunlight has a chemical effect upon smoke which causes the visibility to become worse for 1/2 to 1 hour after sunrise. When such conditions prevail, the pilot will usually find that the visibility is noticeably worse when he is looking into the sun. If the wind is light, it is usually better to land through smoke with the sun at your back, regardless of the wind direction.

ADVECTION FOG

Advection fog results from the cooling of moist air to the saturation point as it passes over a colder ground or sea surface. This fog usually forms over a wide area, and may be as much as 1,000 or 1,500 feet in depth. It generally forms at the ground; but if the wind is strong, a ceiling of a few hundred feet may prevail. Advection fog is most prevalent where onshore winds blow from warm water toward cold land.

Because the cooling which produces the fog also stabilizes the air, a layer of fog-filled air may tend to stagnate, particularly if it comes up against a mountain barrier, and will only dissipate with strong sunshine or with the passing of a front.

Advection fog presents a problem to the pilot because it usually covers extensive areas and is often dense and persistent. Advice of an experienced forecaster should always be sought in planning air operations when advection fog is imminent. The duration of the fog will depend upon several factors, such as cloud cover above, wind velocity, and terrain. The effect of these and other governing weather factors can only be determined by a forecaster who is acquainted with the locality.

Advection fog will usually thin out as it moves over snow at a temperature below freezing. If the temperature of the snow is just at freezing, the fog will become denser. Warm air over snow tends to become less foggy because water is condensed onto the chill surface of the snow. Snow falling through fog will cause it to dissipate only if the temperature is below freezing.

Rain that is warmer than the air along the ground will ordinarily produce or intensify a fog condition. This fact is responsible for most prefrontal fogs.

Section VI

SHOWERS AND SQUALLS

Where rain or snow is falling, ice accretion will almost always be found at some level. Where heavy rain is occurring, and particularly in showers, turbulence will also be found at the level at which the precipitation is originating. This is because the physical process which forms rain requires the presence of ice crystals and water droplets at subfreezing temperatures in the same region of a cloud. These conditions also favor ice accretion. To form heavy rain, extensive lifting of the air is necessary, implying the presence of strong vertical currents and turbulence. However, it would be a mistake to assume that icing and turbulence are not present simply because precipitation is not occurring. Both icing and turbulence frequently occur without rain or snow or any apparent threat of them.

Showers and squalls, because they are relatively small and usually surrounded by clear air, are too often regarded lightly by inexperienced pilots. This is a dangerous attitude, and the history of aviation records its disastrous results. Some of the most severe turbulence and worst icing conditions are encountered in small, localized squalls.

WHYS OF SHOWERS AND SQUALLS

The distinction usually made between a shower and a squall is a fine one, based upon the absence or presence of strong, gusty surface winds and the intensity of precipitation. These are characteristics which can best be observed from the ground, but they are likely to be meaningless for the pilot. Showers and squalls will, therefore, be discussed together in this section.

Both showers and squalls occur in conditionally unstable air; that is, in air which is stable when unsaturated but becomes unstable when saturation occurs. Either type of storm may be produced by surface heating or released by such localized upward displacement of air as occurs over a mountain ridge. Except for a difference in intensity, these two types of storm present similar flight conditions and require the same flying technique.

The intensity of a local storm will be governed by the amount of moisture available and by the amount of energy released when this moisture condenses. The amount of energy released will be large when a steep lapse rate, through a comparatively deep layer of air, indicates that air can rise unstably for a considerable distance. The production of cloud and precipitation will proceed rapidly under such conditions, and the resulting weather is described as a squall. A layer of unstable air at least 10,000 feet thick is usually necessary before a heavy squall can be produced.

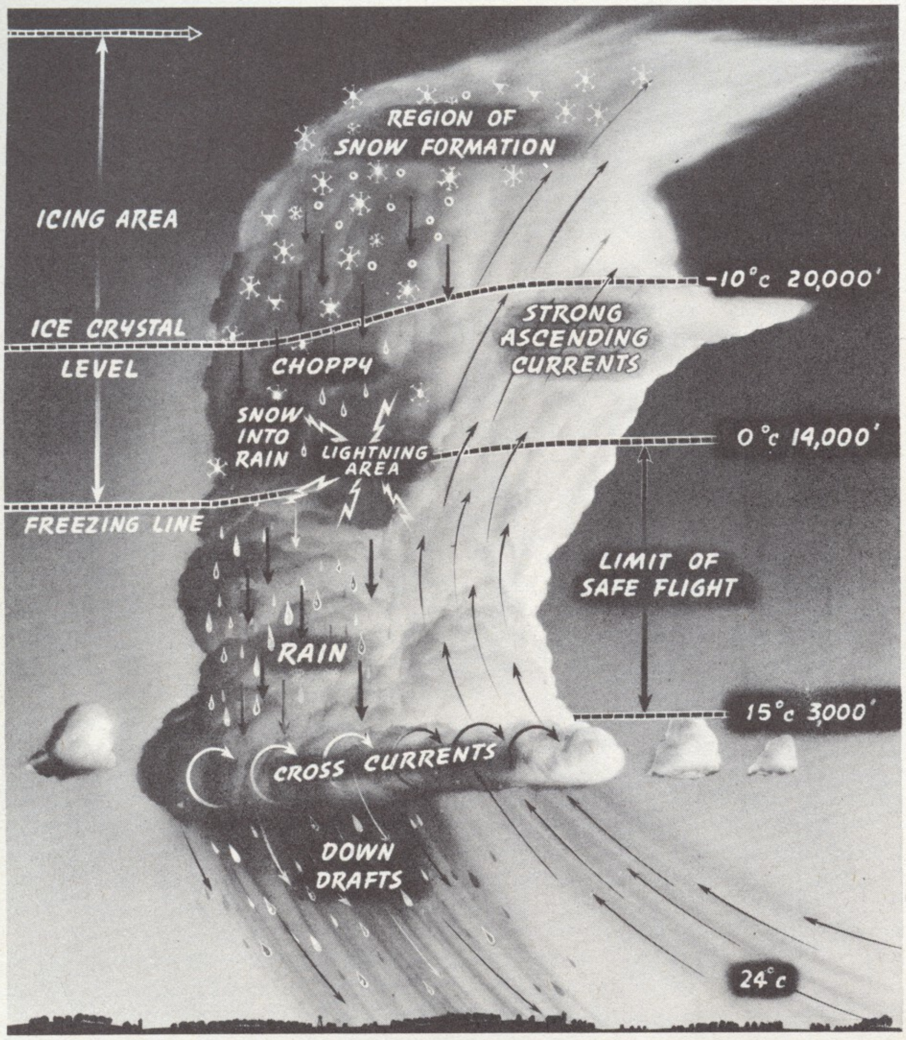
If upper air observations of temperature and humidity are available, the forecaster can usually predict the occurrence and intensity of squalls or showers by noting the steepness of the lapse rate and the amount of water vapor available to provide energy for the storm.

IT'S A QUESTION OF TEMPERATURE

Unstable rising air currents may be started through heating of the surface air by contact with sun-warmed ground, or by upward displacement of a portion of the air. When both factors are active, as on a hot day over the barren mountainous terrain from central Texas westward, violent squalls may be produced. Such storms often remain stationary over a given hill or peak throughout the period of their activity.

The slope of most frontal surfaces is too slight to provide the upward thrust necessary to initiate the formation of squalls; but cold fronts, having relatively steep slope and high speed, form squalls more readily then warm fronts. Showers are more common along warm fronts.

One physical difference between a squall and a shower is in the vertical distance between the base



Structure of a squall in summer: The rain squall should be circumnavigated if possible. If necessary, flight should be conducted through the cloud mass in the rain area or above the ice-crystal level. The intermediate level should be avoided to eliminate the hazard of ice and lightning.

of the cloud and the level at which ice crystals begin to form rapidly (-10°C). Most precipitation is produced at or above this level, hence a heavy shower will develop in and fall from a smaller cloud when the ice-crystal level is low. If the cloud cannot go above this level, no precipitation, or only a light shower of large raindrops, may result.

DANGERS TO EXPECT AND AVOID

Icing conditions will prevail in the upper regions of all squalls and most showers. The temperature gage or upper air temperature observations will tell the pilot the altitude of the freezing level, below which icing will not occur.

The intensity of the storm is determined mainly by the rate of decrease of temperature with altitude, and this same condition determines the vertical velocity of ascending air. The degree of turbulence may be anticipated with reasonable accuracy by determining the lapse rate before the flight. Since the lapse rate in a squall is steeper (decreases more rapidly) than in a shower, turbulence is most severe in a squall. Similarly, since the size of individual cloud droplets and the quantity of water suspended in a cloud is determined by the velocity of the ascending air, the rate of ice formation will be determined by the steepness of the lapse rate. Therefore, ice accretion is usually more severe in squalls than in showers.

KNOW THEIR LIFE HISTORIES

A squall or shower has a definite life history. It grows, reaches maturity, becomes old and weak, and finally dies. The intensity of turbulence and icing conditions is directly related to this cycle. The age factor must always be considered. A pilot who has formed his ideas of the intensity of hazards in squalls from experience with old or decadent storms may get a dangerous or even disastrous surprise when he meets a squall at the peak of its maturity.

Squalls and showers reach their peak of violence early in life, just when the cloud attains its maximum height, and rain or snow begins to fall from the base. Thereafter, the intensity of turbulence and ice accretion slowly decreases. This decay is usually indicated by a fading of the sharp outlines of the cumuliformed summit of the storm cloud. This fading usually progresses downward from the upper portion of the cloud.

The energy that sustains a squall or shower is derived solely from the air fed into it at its base. No appreciable quantity of air enters the cloud at intermediate levels. Consequently, such storms have a tendency to develop rapidly and to be short-lived, soon declining when the supply of warm air at the ground is exhausted or cut off. Showers and squalls, therefore, occur as localized storms.

The heavy precipitation which occurs as the squall or shower reaches maturity carries colder temperatures downward. Locally chilled air sinks within the storm, interrupting the progress of ascending air and diminishing the intensity of the storm's development. However, when precipitation is encountered in a squall or shower, violently choppy and bumpy air, as well as drafts, will usually be found.

BETTER GO ANOTHER WAY

Near the base of the cloud, the ascending air about to enter the storm is strongly repulsed by the cold descending air, and strong cross-currents are produced. This region of a squall or shower should be avoided if possible.

When precipitation falls from the base of a cloud the unsaturated air beneath is cooled by contact and evaporation. Being then colder than the surrounding air, it will fall unchecked to the ground, producing a strong downdraft.

Because the onset of heavy precipitation from a squall or shower is usually sudden and the area of activity small, these downdrafts are often strong enough to throw an airplane out of control or possibly carry it into the ground.

WHERE LIGHTNING STRIKES

Records reveal that the majority of lightning strikes involving aircraft have occurred in squalls or showers, when the airplane was flying at a level where the temperature was near freezing. This region should always be avoided. Just below the freezing level, the snow which formed in the upper portion of the cloud changes to sleet and rain. During this process, a concentration of electrical charge occurs. It usually dissipates by natural means; but an airplane moving through the region may serve as a conductor to shorten the electrical circuit between oppositely charged portions of the cloud, causing a lightning discharge.

The major lightning hazard is temporary blindness by the brilliancy of a nearby discharge. Guard against this danger.

Because the precipitation usually begins suddenly in a squall or shower, the electrically charged region is formed rapidly and the charge is accumulated faster than it can dissipate by natural means. The lightning danger is, therefore, greatest when the storm is at its peak of activity.

THE LIGHTNING HAZARD AND PRECAUTIONS

There are usually several warning signs when a lightning discharge is about to occur; and the pilot, being forewarned, can take proper precautions to avoid it or minimize its effect. When flying through squalls, showers, or even towering cumulus clouds, a lightning discharge should be anticipated whenever:

1. The temperature is between 5° and $-10^{\circ}C$.

2. Mixed rain and snow is encountered.

3. Severe static occurs in the radio.

4. Corona forms on the propeller or other parts of the plane.

To avoid or minimize the effects of a discharge:

1. Seek a lower altitude.

2. Reduce speed to 50 percent above stalling speed.

3. Keep eyes focused on instruments, which should be brightly lighted at night.

4. Have automatic pilot adjusted for level flight and ready to engage. You may be temporarily blinded and the compass made inaccurate by a lightning discharge.

MOUNTAINS AND FOOTHILLS ARE BREEDERS

The upward thrust of air required to initiate a squall or shower can be produced by an abrupt slope of the terrain, forcing air flowing over it upward to the condensation level. Squalls and showers are, therefore, common over mountains whenever conditionally unstable air moves across them.

A storm over a ridge or mountain will generally remain stationary instead of drifting with the air flow. It grown continuously on its upwind side, becoming old and dissipating progressively on its downwind side in the lee of the mountain or ridge. The most rapid cloud growth, with its turbulence and icing, will occur over the summit, and the heaviest precipitation on the lee side. When a downdraft occurs on the lee side of a hill in conjunction with a shower or squall, the strength of the downdraft is added to the normal down-slope flow over the obstruction. Downdrafts over rough terrain are, therefore, more intense than over level ground and should be avoided.

In the same way, rising currents initiated in mountainous regions by heating of the ground are intensified on the windward slopes of mountains so that updrafts and turbulence will be accentuated there.

Foothills and low mountain ranges whose crests are below the cloud bases are notorious for violent squalls. The Allegheny mountains in the eastern United States are an excellent example.

Idealized diagrams can be made showing the structure and development of squalls and showers. These structures should be studied carefully and the hazardous regions of the storm memorized.

FLIGHT RULES TO BRING YOU THROUGH

From study of the structure and characteristics of squalls and showers, a number of flight rules can be derived. If a pilot learns them and applies them, the hazard of flight in these storms can be virtually eliminated. First let us review the problems to be met. They are:

1. TURBULENCE.

Always present, most severe during the early part of the storm's activity.

In the region of ascending currents, strong drafts predominate.

In the region of falling snow or rain, the air is choppy and bumpy.

In the base of the cloud, buffeting turbulence may be expected.

Downdrafts are found in the region of precipitation below the base of the cloud, and may occur elsewhere.

2. ICE.

Moderate ice is to be expected in all portions of the cloud where the temperature is below freezing.

Glaze usually occurs in regions of ascending air.

Rime usually occurs in the region of precipitation.

3. LIGHTNING.

Always possible near the freezing level.

4. PRECIPITATION.

Rain or snow, depending on the temperature. Moderate to heavy, localized, and usually of short duration.

RECOMMENDED FLIGHT PROCEDURES

1. Fly around all squalls and showers at a level above the base of the cloud.

2. If it is absolutely necessary to go through the storm without de-icing equipment, fly at an altitude above the turbulent base but below the freezing level. Before entering the cloud:

Apply carburetor heat.

Secure safety belt.

Reduce speed to 50 percent above the stalling speed.

Establish heading on gyro compass.

If the plane is equipped with de-icers, perform the above operations upon entering the cloud.

Hold heading.

Maintain lateral balance by easy control.

Ride with the vertical currents.

3. Do not:

Dive out of a squall or shower.

Dive under a squall or shower to maintain ground contact.

Attempt to turn out of a storm, except as a last resort.

Fly at a level where the temperature is near freezing.

Section VII
THUNDERSTORMS

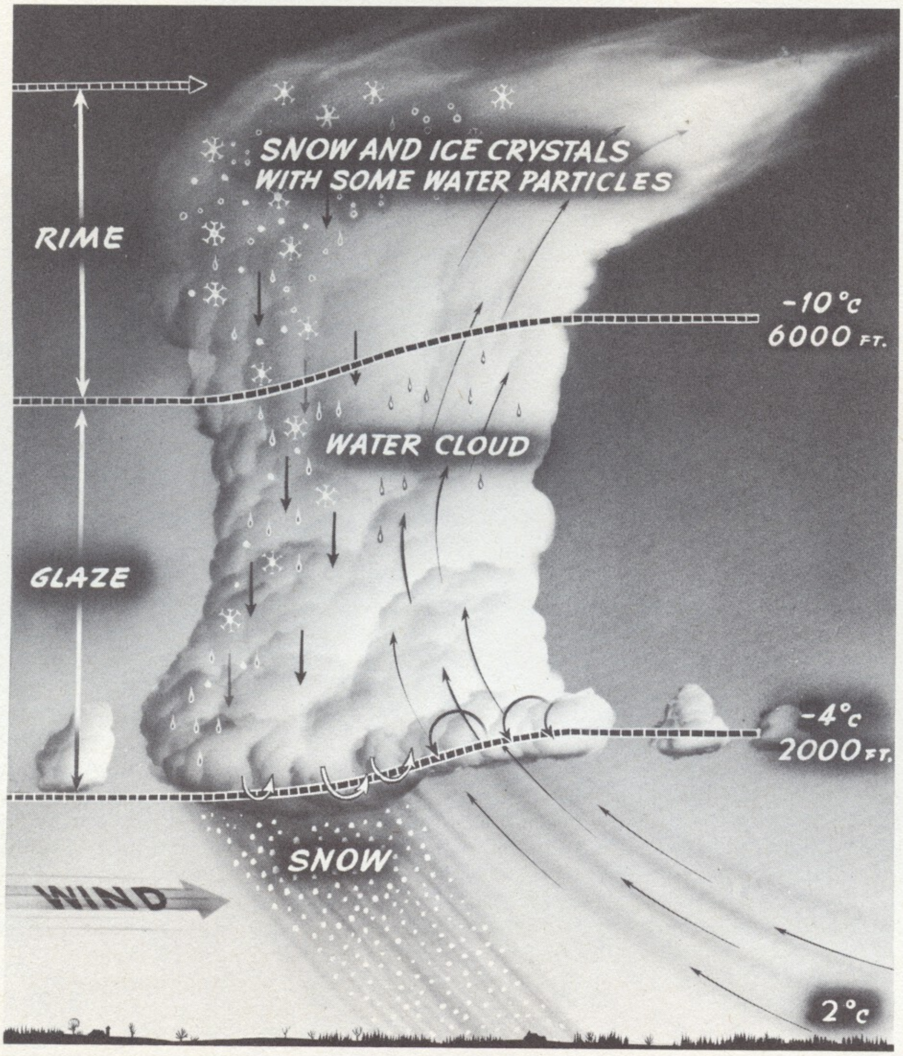
A thunderstorm is formed by the same processes as a squall and has many of the squall's characteristics. The major differences are greater intensity, larger size, and more lightning and thunder.

Flight through a thunderstorm should be avoided whenever possible. However, there are times when there is no alternative, and it is, therefore, essential that a pilot know the various types of thunderstorms so that he may select a safe flight path. On his first flight through a thunderstorm, the average pilot will not find any path much to his liking. However, if he keeps cool, he will undoubtedly discover that his fear (and that is what it is) does not result from his actual predicament at the moment. He is afraid of imaginary dangers he visualizes ahead. Passage through the average storm, regardless of type, is rough. Rain will be heavy, lightning brilliant, and turbulence variable, usually moderate to severe. These conditions demand constant alertness, and the pilot must also be on the watch for the hazards of icing and hail. The dangers which an airplane may encounter in a thunderstorm are loss of control, loss of power, and damage by hail, lightning, or extreme turbulence. These dangers can all be foreseen, and precautions can be taken to minimize their effect.

ELEMENTS TO KNOW AND REMEMBER

The elements that are potentially dangerous are:

ELEMENT	OCCURRENCE	REGION	REMARKS
Turbulence	Always	Throughout storm	Severe in updrafts, moderate to mild in other regions.
Ice accretion	Always	Above 3° C level	Can become severe at low temperatures or in rain area where temperature is below freezing.
Hail	Rare	At sides and front	Usually occurs in clear air at sides and front of central cloud mass. Hail encountered within the cloud is usually soft and small.
Squall winds	Frequent	Along front of storm	This element hazardous only if flight is conducted at low levels or landing or take-off is made at time of occurrence.
Lightning	Frequent	Throughout storm	Injury to aircraft will be limited to small structural burns or fusings, but from the operational standpoint the hazard is real since radio and electrical equipment will probably be knocked out just when they may be most needed. However, the chance of a discharge striking an airplane in flight is remote.



Structure of a squall in winter. - Ice accretion can be particularly heavy in the base of snow squalls when the temperature is between 0° and -10°C. Winter squalls may be flown through at upper levels and only a light to moderate amount of ice accumulated. Turbulence is usually of the same degree.

When flying through a thunderstorm, a pilot should avoid regions of hail, squall winds, and icing conditions, and seek to minimize the hazards of turbulence and lightning. He should always get the advice of a forecaster when planning a flight through an area where thunderstorms are present or probable. In this way he is prepared for a certain type of storm and can make his flight plan accordingly.

HOW A THUNDERSTORM GETS THAT WAY

The energy that creates and maintains a thunderstorm comes from the liberation of latent heat, as water vapor is condensed by the expansional cooling of the air as it rises. The rate at which energy is released, and consequently the intensity of the storm, is determined by the quantity and moisture content of the ascending air, the depth of atmosphere through which it rises, and the degree of instability. The degree of instability is indicated by the lapse rate, the amount of vertical rise by the thickness of the unstable layer, and the amount of moisture available by the specific humidity of the air. One other element that contributes to the intensity of a thunderstorm is the strength of the impulse that initiates the rising current. Cold fronts and abrupt changes in the slope of the terrain frequently cause thunderstorms in air which would otherwise be free of them, and greatly increase the intensity of thunderstorms which may originally have been moderate. Changes of intensity may occur very rapidly.

LIFE HISTORY OF A THUNDERSTORM

As in rain squalls, turbulence and ice accretion are the two major hazards in thunderstorms. Rain, lightning, thunder, squall winds, and hail all result from the activity that produces the storm. They do not contribute to the development of the storm, but they do present flight problems. The important point is that the intensity of any one or all of these subsidiary elements cannot be taken to indicate the intensity of turbulence or ice accretion.

A thunderstorm may be divided into distinct zones or regions, both vertically and horizontally. Each zone will be characterized by the predominant type of cloud particle, precipitation form, or intensity of turbulence.

The age of the storm is also important. Different intensities of turbulence characterize different phases in the life of the storm. Different types of storms have different rates of development and durations of activity.

The life history of a thunderstorm falls into three periods:

FROM VAPOR TO CLOUD

1. PERIOD OF DEVELOPMENT.

This period begins with the initial development of cumulus clouds and ends with the onset of rainfall. During this period, the ascending currents steadily increase in strength and size, reaching a maximum just before precipitation begins - that is, shortly after the upper portion of the cloud reaches the level where its temperature falls to -10°C and the production of ice crystals become copious. At this period lightning does not occur naturally, but it may be possible for an airplane flying through the cloud near the freezing level to bring about a discharge.

During the period of development, the ascending air is not held back by falling precipitation; consequently, very strong drafts are experienced, even at low levels. The drafts, however, need not be large or sustained, particularly if the instability is great. A very choppy type of turbulence results which, together with local strong gusts, has probably made many a pilot ask himself what happens in a well-developed thunderstorm if an infant thunderstorm can be so rough.

FROM ICE NEEDLE TO RAINDROP

2. PERIOD OF PRECIPITATION.

In a thunderstorm, a raindrop begins life as an ice needle or crystal in the portion of the cumulonimbus cloud above the freezing level. Gradually this crystal develops into a snowflake, and as it falls through warmer air it increases in size and weight. After passing the freezing level, the snowflake melts and falls through and out of the cloud as rain. A heavy fall of precipitation exerts a considerable downward drag on the air through which it falls. Also, the snow melting to rain and the precipitation falling from the cold upper part of the cloud, chill the lower air. This results in downward currents of air in the region of falling precipitation which oppose and damp out the rising currents. The conflict of currents produces choppy air with gusts of irregular size. Flight through the precipitation area is, therefore, uncomfortable but by no means hazardous, so long as control of the airplane is maintained.

In the front of the storm, the path of ascending air currents remains unobstructed, and strong sustained drafts prevail. This region is clearly marked by boiling and rolling cloud motions and should be avoided.

FROM RAINDROP TO PUDDLE

3. PERIOD OF DISSIPATION.

A thunderstorm begins to dissipate when the source of energy is cut off, and when the air within the cloud is made stable. Regardless of the primary cause, dissipation will occur only when the ascending currents within the storm are destroyed. The cloud then loses its extremely dense and boiling appearance, particularly in the lower portions below the freezing level, and becomes ragged and diffused.

As the lower portion of the cloud begins to dissipate, evaporation of the liquid water tends to cool the air, causing it to settle until it reaches more stable air. Since falling precipitation and melting snow are capable of cooling the air at intermediate levels, downdrafts are usually most intense during the dissipating period of the storm. These drafts may carry an airplane down as much as 2,000 feet in a very short space of time.

ALL SORTS TOGETHER

Certain types of storm are continually growing in the forward portion, reaching maximum development somewhere in the middle of the storm cloud, and dissipating in the rear. All three periods in the development, therefore, may be exemplified in a single thunderstorm. From the form and appearance of the clouds in the various portions the pilot can judge the state of development of each section of the storm. Furthermore, there is no guarantee that because one portion of the storm is obviously dissipating, other portions may not present different problems.

FOUR FLIGHT PROBLEMS

From the discussion so far, it is apparent that a thunderstorm presents a continuous series of weather problems throughout its history. A developing or decaying thunderstorm may be quite as uncomfortable to fly through as a well-developed storm.

A thunderstorm may be divided into four zones or layers one above the other, each characterized by the type of cloud particle and precipitation form found there. Each zone presents its own flight problems. The zones are:

DOWN UNDER

1. WATER-VAPOR ZONE.

The lower limit of this zone is the surface of the earth and its upper limit is the base of the cloud. It is a region of considerable turbulence. Ascending gusts will be present in the forward portion of the storm and choppy air in the precipitation area, with strong downdrafts and squall winds between these regions. In and behind the rain region, strong sustained downdrafts may be encountered, particularly if the storm is decadent.

The water-vapor zone is free of cloud, but rain and soft hail fall through it. Visibility is usually good, but a real downpour will reduce the visibility locally almost to zero. The temperature is well above freezing. When the heaviest rain can be avoided, flight through this zone is favored only if the ceiling is ample for contact flight. The downdrafts associated with the "storm collar" should be avoided, and the flight path should angle in from the side.

WATER UP THE CHIMNEY

2. WATER ZONE.

The lower limit of this zone is the cloud base and its upper limit is the freezing level. It is occupied by cloud and falling precipitation whose particles, with the exception of hail, are all in the liquid state. The lapse rate within this zone follows the moist adiabat.

During the period of development the water zone is a chimney of air ascending at high velocity. When precipitation begins, rapid ascent of the air continues in the forward part of the cloud but in the area of rain the updrafts are damped out, the air remaining choppy. The interior of a cloud is usually very dark even at midday, necessitating the use of instrument lights.

Strong updrafts may be encountered both in the water zone and in the clear air ahead of the storm. Downdrafts may be encountered at the same level in clear air behind the storm, particularly if there are occasional showers falling from a higher cloud level.

WATER BELOW FREEZING

3. SLEET ZONE.

The lower limit of the sleet zone is just below freezing level, and its upper limit is at the level where the temperature is -10°C. Within the sleet zone, the cloud is made up predominately of water droplets, with some ice crystals in the upper portion. The precipitation form is snow, which turns to rain in the extreme lower portion. Some rain will also be carried back up into the sleet zone in its forward portion where the ascending currents are strong.

NOTE

The term sleet as used here, means a slushy wet snow, usually a mixture of snow and water, frequently observed in convective clouds near the freezing level.

The sleet zone is marked by continued strong ascending currents in the forward portion. Since the cloud droplets remain liquid, ice will accumulate rapidly on an airplane. If the plane has accumulated a coating of ice in the front of the storm, ice will continue to build up in the sleet zone. This accumulation may be extremely hazardous, since sleet usually creates a rough, uneven surface with blunt protuberances frequently 2 to 4 inches long.

In the sleet zone, the hazard of icing increases with altitude. Therefore, if flight must be made through this region, it should be made through the lower portion of the zone, and the de-icers should be operated continuously.

NOT SO BAD

The lower limit of the sleet zone will usually be indicated by the presence of a horizontal cloud collar which is common to most thunderstorms at intermediate levels. This cloud collar usually has the form of stratocumulus with its base often between 10,000 and 14,000 feet, although in desert regions it may be much higher. It may extend a mile or more ahead of the cumulonimbus. The freezing level will be about 1,000 feet above the top of this cloud deck. As a rule, turbulence is less violent in this region, and many experienced pilots consider it the safest level for flight through a thunderstorm. The air will be choppy, but the presence of sustained updrafts is rare, icing is infrequent, and the downdrafts are weak or absent.

The relative inactivity in this zone is due in part to the melting of the snow when the plane passes through it. It requires heat to melt the snow; this heat is absorbed from the air, which is, therefore, cooled. This air, momentarily made denser, tends to sink. The air becomes more stable, and the turbulence, therefore, diminishes.

Thunderstorms that produce prolonged heavy rain can by this process even develop an inversion near the freezing level. This restricts or deflects the ascending air sufficiently to project the cloud outward horizontally and so reduce turbulence.

ICE-CRYSTAL ZONE THE HIGHEST

4. ICE-CRYSTAL ZONE.

The lower limit of this zone is the level where the temperature is approximately -10°C, and the upper limit is the upper limit of the cloud. The ice-crystal zone composes the "anvil head," that is, the upper spreading portion of the cloud, in which ice crystals predominate although many liquid water droplets remain in suspension. The clear cut, boiling contour typical of the lower portions of the cumulonimbus clouds is never found in this region, the cloud having a fibrous or filmy appearance.

The lower limit of the ice-crystal zone is usually above 20,000 feet. The pilot seldom has occasion to enter the clouds at this level, since the heads of the thunderstorms are surrounded by clear air and can easily be avoided. Within the clouds, turbulence is moderate to severe, with large drafts still present in the forward portion and irregular choppy air motion elsewhere.

Moderate icing conditions, with rime predominating, occur in the ice-crystal zone, particularly in the forward portion of the cloud.

There is ample evidence that the region where hail is formed lies in the forward portion of the ice crystal and sleet zones, where the ascending currents are powerful enough to carry along large ice particles with them. The normal path of the ascending air curves upward into the side and forward point of the "anvil," so hailstones usually fall through clear air once they have escaped from the updraft. In the lower front portions of the storm, the air is moving toward the cloud mass; therefore, the path of falling hail slopes toward the cloud, and in many instances it will pass behind the cloud collar and fall with the first gush of rain.

Study of many records of flights through thunderstorms shows that most cases of serious damage from hail occur IN THE CLEAR AIR NEAR THE STORM.

KNOW THESE THUNDERSTORM CLASSES

Thunderstorms are classified according to the agency that initiates the upward thrust of air and releases its instability. Classifying thunderstorms simplifies their study. The class of thunderstorm can be determined by studying the weather map. Before leaving the ground, the pilot should know what sorts of thunderstorm he may encounter.

Thunderstorms are classified under two main headings, and the various subtypes may be grouped under these headings.

FRONTAL	AIR MASS
Warm front	Thermal
Cold front	Overrunning
Prefrontal	Orographic
	Advective

This classification is not absolute, and there is always a possibility of two or more agents combining to intensify activity. For example, the arrival of a cold front against a mountain barrier will generally increase thunderstorm activity along the front. Likewise, air mass thunderstorms of the thermal type will rapidly dissipate upon moving from warm land out over a colder water surface, or intensify over a city or some barren surface where heating is exceptionally strong.

It is not correct to assume that frontal lifting is the only agent initiating frontal thunderstorms, or that all air mass types result from surface heating. Combinations of circumstances may be very complex.

STAY UNDER WARM FRONTS STORMS

Warm front thunderstorms are initiated by the upward thrust of the air as it moves up-slope over a warm front surface. Because the slope of a warm front is usually small, and because the thunderstorms cannot feed on air entering them from beneath the frontal surface, warm front thunderstorms seldom attain the size and violence of other types. The cold air under the frontal surface does not play any real part in the storm's activity, so flight below the base of the cloud is the accepted procedure.

Warm front thunderstorms can, however, become extremely intense under certain conditions. One such condition is when a warm front has been dormant. During this dormant period, clouds may be scattered or totally absent with the stability of the air in fine balance. The sudden release of energy when the stability is upset develops thunderstorms along the front with astonishing rapidity. There have been numerous occasions when, within an hour, a front 500 miles in length has become a solid thunderstorm region 200 miles across.

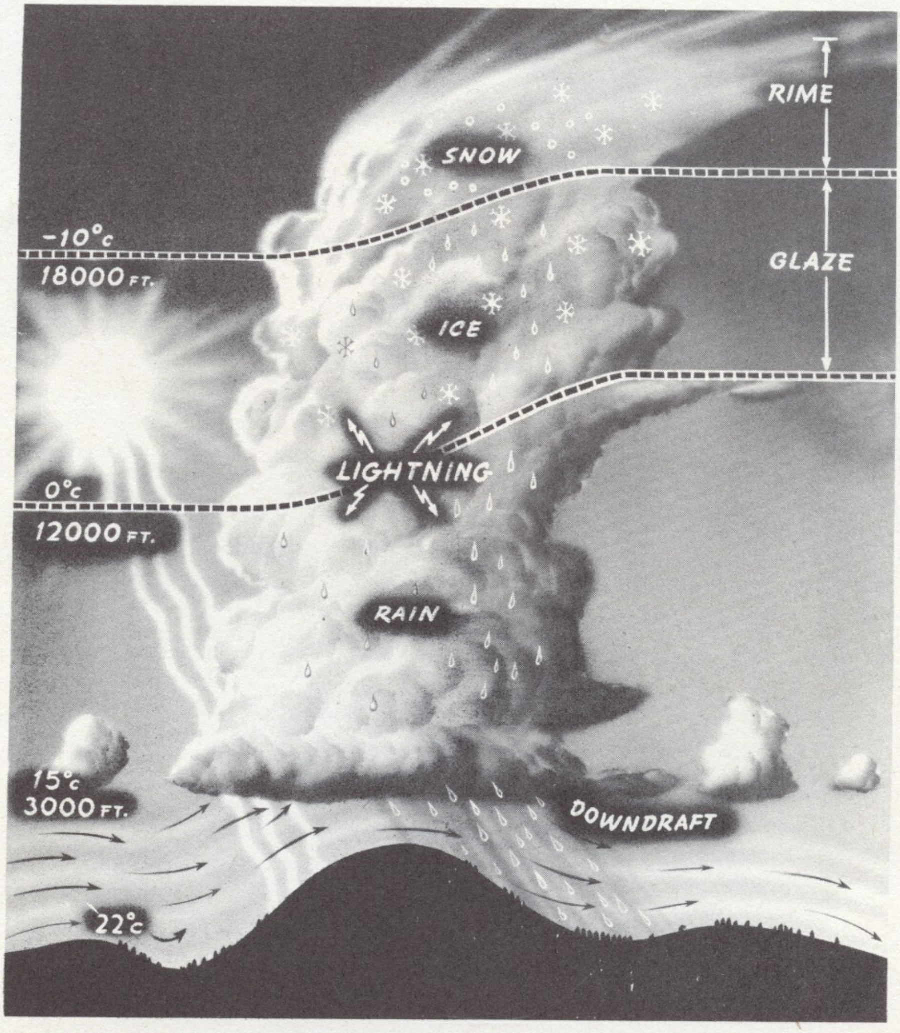
Strong upward drafts will persist within warm front storms during their formative period. However, the bottom of these drafts is at the level of the cloud base, and they will not be encountered in flight below the base.

Warm front thunderstorms may be encountered unexpectedly while flying on instruments through the frontal cloud mass. Watch for them closely. The presence of thunderstorms is indicated when "crash" static is heard in the radio or a change in cloud structure from nimbostratus to cumulonimbus is observed. When flying between layers, a column of turbulence, boiling clouds connecting layers will be indicative of thunderstorms, particularly if other conditions are favorable.

SUMMARY: Warm front thunderstorms are rarely intense enough to be dangerous, except during the initial period of their development. Hazards associated with them can be avoided by flying below their bases. At intermediate levels, hazards can be minimized by use of the procedures for flying turbulence.

HEAR HERE, STEER CLEAR

Cold front thunderstorms are a very severe type. The hazards associated with cold front thunderstorms



Orographic squalls. - The combined effects of orographic lifting of the air mass and surface heating frequently produces intense squalls having strong downdrafts below the cloud base on the lee side. Such storms should always be topped or circumnavigated: never flown under.

are not limited to turbulence and icing within the clouds. Low ceilings, severe turbulence extending to extremely high levels, and the presence of several storms side-by-side forming a long impenetrable wall may be expected. Except at altitudes above 20,000 feet, it is usually impossible to fly around them.

The extreme severity of cold front thunderstorms results from a combination of factors. The slope of the front is steep and the upward thrust of the air is consequently sudden; also, convergence of the warm air ahead of the front increases its instability. Consequently, the intensity of a cold front thunderstorm is greater when:

1. The instability of the warm air is great.

2. The difference in temperature across the front increases.

3. The angle between the isobars in the cold sector and the cold front increases.

4. The cold front moves rapidly.

The cold front type of thunderstorm presents the most difficult problem in selecting a suitable flight path. This is because of the number of factors involved and of the variable intensity of these factors. The pilot must rely upon common sense and experience in establishing a sound flying technique.

Over mountainous terrain, great care must be used in attempting to fly through cold front thunderstorms. Unless flight can be made over the top or between towers of clouds, it is safest to land and wait until the front has passed.

BUT IF YOU MUST

If flight must be continued into and through cold front storms, the following procedures are recommended:

1. Climb to an altitude above the stratocumulus collar. This will usually be above 8,000 feet. This altitude should be attained before approaching the storm.

2. From this altitude, the contour of the cloud domes can be determined. Choose a path where the domes are lowest. Select your magnetic heading and set the gyro before going on instruments.

3. Reduce air speed to 50 percent above stalling speed and take other precautions for flight in turbulence.

4. Upon entering the cloud, maintain your heading. If extreme turbulence or other really dangerous conditions are encountered, make a gradual turn out of the storm.

DO NOT

1. Change altitude to seek smoother air.

2. Change course after penetrating the depth of the storm. Such action might take you away from your planned path into the center of a more active zone.

3. Attempt to fly underneath the storm, especially if there are dust clouds or other indications of a strong squall wind.

4. Hesitate to turn back and land if the storm appears too tough.

EXPERIENCED PILOTS RECOMMEND

Experienced pilots, in addition to the procedures above, consistently recommend:

1. Choosing a flight path at any altitude where rain or lightning is heavy.

2. Avoiding hazy, greenish-hued, light spots in the cloud mass.

3. Angling into the squall cloud from the side, thus avoiding the region of strongest updraft.

4. Never flying at a low altitude between two towering active cumulonimbus clouds.

5. Avoiding the combination of icing conditions and turbulence.

THE MOST VIOLENT OF ALL

Prefrontal thunderstorms occur in the warm sectors of active cyclones ahead of well-defined cold fronts. They are ordinarily found between 100 and 300 miles ahead of the cold front. Because of the similarity of characteristics, prefrontal thunderstorms are frequently mistaken for the front itself, and a pilot may thus encounter thunderstorms far in advance of the estimated position of the front.

Prefrontal thunderstorms are caused by the combined effects of conditional instability, intense surface heating, and convergence of inflowing winds. The storms usually develop early in the afternoon and dissipate after midnight. They may recur on several successive days at approximately the same distance ahead of the cold front.

Because of the combination of conditions producing prefrontal thunderstorms, they are the most violent type of storm. When tornadoes occur it is usually in conjunction with prefrontal thunderstorms, an indication of the extreme degree of instability. The rapidity of their movement, their occurrence as a line of storms, and the usually violent wind squalls, torrential rains, and often hail, have earned for a line of prefrontal thunderstorms the common name of "line squall." This term is also applied to cold front thunderstorms.

It is freely claimed by experienced flyers that prefrontal thunderstorms combine all the hazards to aircraft, on the ground or in the air. They deserve the respect of every pilot.

PREFRONTAL STORMS COME UP FAST

One feature of prefrontal thunderstorms, often not sufficiently emphasized, is the element of surprise in their extremely rapid formation. During the forenoon, there may be no visible evidence of the pertending development. In the early afternoon, cumulus clouds will form and dissipate. By midafternoon, the squall line will have formed suddenly from the remmants of fair-weather clouds and may extend for hundreds of miles, an unbroken barrier. Experienced forecasters can, with the aid of upper air data, anticipate the formation of prefrontal thunderstorms and estimate closely their position and rate of movement. This is difficult for the average pilot, but the following hints may be of value:

Prefrontal thunderstorm will occur only when the morning or noon map reveals:

1. A well-defined cyclone with an open warm sector.

2. Isobars in the warm sector curving from an east-west orientation to a northeast-southwest orientation.

3. An area of falling pressure in the warm sector.

4. No heavy cloud cover in the warm sector to limit solar radiation.

Prefrontal thunderstorms will form along a line parallel to the cold front and passing through the center of the area of falling pressure. The direction of the warm sector isobars will usually change most sharply from an east to a northeast direction along this line.

Although prefrontal thunderstorms ordinarily form within 50-100 miles of the cold front, because of their rapid movement, they may be 300 miles ahead of it before they dissipate at night.

The line squall. - This type of storm can be exceptionally rough, but when flown through at right angles is usually of short duration. Do not parallel it. Flight just over the roll cloud or on top if conditions permit, is the proper procedure.

The prefrontal thunderstorm squall line seldom, if ever, terminates in the center of the cyclone. Usually it fades out 100 to 200 miles short of the center. It rarely extends more than 600 miles from the center, so its average length will be about 400 miles.

BREAKS TO GET THROUGH

Along a squall line there are usually breaks through which flight can be made at a practicable level. However, unless such a break is found "on course," a search is generally useless; and it is good policy to land and wait for the squalls to pass, or to delay until the storm dissipates.

One noticeable peculiarity of prefrontal thunderstorms is the extremely violent updrafts occurring in the clear air ahead of the squall line. These drafts may be expected 5 to 10 miles in advance of the cloud mass, and if the pilot has not already decided to turn back, the initial encounter with turbulence will usually help him to make up his mind. When approaching prefrontal thunderstorms, therefore, the precautions for flying in turbulent air should be taken while still some distance from the cloud. All the hazards of turbulence may be encountered in a matter of seconds.

To sum up, don't take chances. Unless flight can be conducted through the active area under blue sky, land and wait for the squall to pass, protecting the airplane well against high winds.

Only two favorable comments can be made regarding line squalls. Their occurrence is infrequent; and they rob the following cold front of some of its most disagreeable weather.

AIR MASS THUNDERSTORMS

A thermal or convective thunderstorm is formed by the same process which creates a rain squall, and it possesses similar characteristics. Individual storms of this type generally cover a larger area, producing lightning, thunder, and sometimes hail. It is the common type of thunderstorm referred to by the popular terms, "thundershower," "thundersquall," "heat thunderstorm," and "local thunderstorm."

The upward thrust of air which initiates a convective thunderstorm is due to heating of the air at the ground by solar radiation. Consequently, moderate to severe turbulence exists below and in clouds as a result of strong ascending air currents. For the same reason, convective thunderstorms form most frequently during the warmest part of the afternoon. They almost always dissipate before midnight.

A convective thunderstorm is usually a good rain producer. One must, therefore, expect strong downdrafts and local squall winds beneath the storm. Since the source of warmth is often purely local, this type of thunderstorm may form and dissipate quickly. In some regions, thunderstorms consistently form over the same area at the same time of day, other conditions being favorable.

BETTER GO CLEAR AROUND

Because of the localized nature of convective thunderstorms, they may be avoided by flying around them. Flying under the storm is not recommended, since convective currents produce moderate to severe turbulence below the cloud base; the visibility may be lowered by heavy rain, and there is the additional hazard of strong downdrafts.

In the tropics, where humidity and solar heating are both extreme, convective thunderstorms attain their greatest violence. In these regions, they should be avoided particularly at night, when they may be hidden by haze or smaller clouds and met unexpectedly, producing complications which might result disastrously.

OVERRUNNING STORMS ARE HIGHER

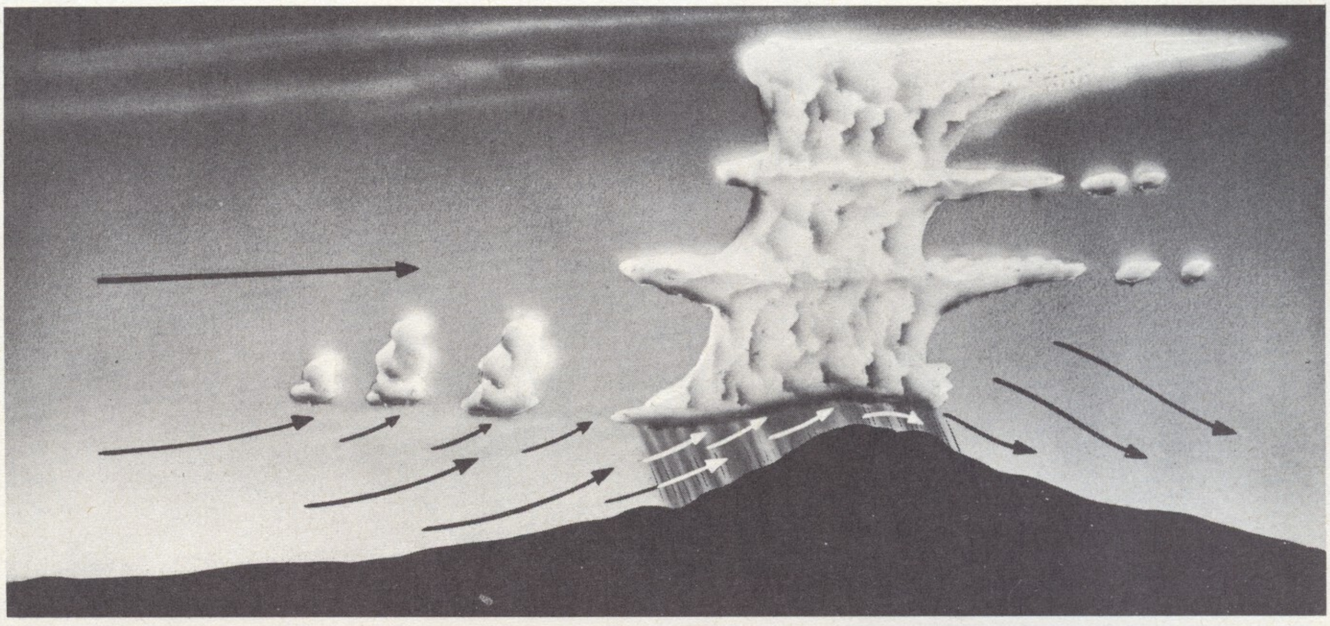
Overrunning thunderstorms are produced by the gradual cooling of the upper layers of an air mass flowing inward and upward over the cool core of a high-pressure area. They are predominately a high-level phenomenon, and their bases are, as a rule, above 6,000 feet. Since surface heating is not involved, this type of storm may occur at any hour of the day or night.

In the northern hemisphere, overrunning thunderstorms are most common on the west and north sides of warm high-pressure areas where warm moist air from the tropics is carried aloft in the anticyclonic circulation. However, since surface fronts do not contribute to the formation of such storms, it is difficult to forecast the probable regions of their activity unless adequate upper air data are available.

FLYING UNDER BASE USUALLY SAFE

Overrunning thunderstorms are usually not large. They move in the direction of the winds at the upper levels. They may come from the south, west, or north, depending upon the wind circulation at the moment.

It is usually easy to fly around an overrunning type of thunderstorm, but flight can be made beneath its base without danger of more than light to moderate turbulence when passing through the rain. If flight must be made through the storm, the general procedures already outlined for flight through a thunderstorm should be followed.



Orographic thunderstorms usually remain stationary, but may dissipate and re-form over the same mountain on several succeeding days. They should always be circumnavigated or flown through at high levels.

OROGRAPHIC MEANS MOUNTAIN-GROWN

Orographic thunderstorms are initiated by the upward thrust of air as it flows uphill. In many respects, this type of thunderstorm has the same characteristics as a convective storm. The same flight procedures should, therefore, be employed.

Orographic thunderstorms will be most intense where the ground slopes up steeply. In southwestern United States, where the mountains are close to the source of moist, conditionally unstable air, this type of storm occurs with clocklike regularity when the wind circulation is favorable. Because of the path of the wind and the relative height of the terrain, the daily storms will localize over certain hills, producing rain of cloudburst proportions and remaining nearly stationary. They will dissipate only when the wind circulation has been interrupted or the instability exhausted.

DON'T GET UNDER OROGRAPHICS

Convention of warm air from the ground does not ordinarily contribute to the intensity of an orographic thunderstorm. Nevertheless, flight beneath the bases of such storms is not recommended because of the force of the ascending air on the windward side; and because the descending air to leeward produces sufficient turbulence to create a definite hazard in mountainous country.

It is best to fly around orographic thunderstorms; but if there is plenty of ceiling and the storm is a high-level type, flight beneath the base may be attempted if the pilot is on guard against updrafts and downdrafts. Great care must be used in flying through orographic thunderstorms in mountainous country. In fact, all thunderstorms, whatever their cause, in the vicinity of mountains should be avoided when possible as they have a habit of enshrouding mountain peaks.

NIGHT STORMS MAY BE ADVECTIVE

Advective thunderstorms are common in the middle western states of the United States. They result when a saturated air mass is overrun by conditional unstable air. When this occurs, thunderstorms develop rapidly and will continue until the instability is exhausted. Advective thunderstorms occur most frequently at night and are definitely of the high-level type.

This type of thunderstorm may be avoided by flying around it, since the activity is generally local. Flight beneath the base of the storm is also recommended, if adequate precautions are taken to reduce the hazard of possible downdrafts associated with rain.

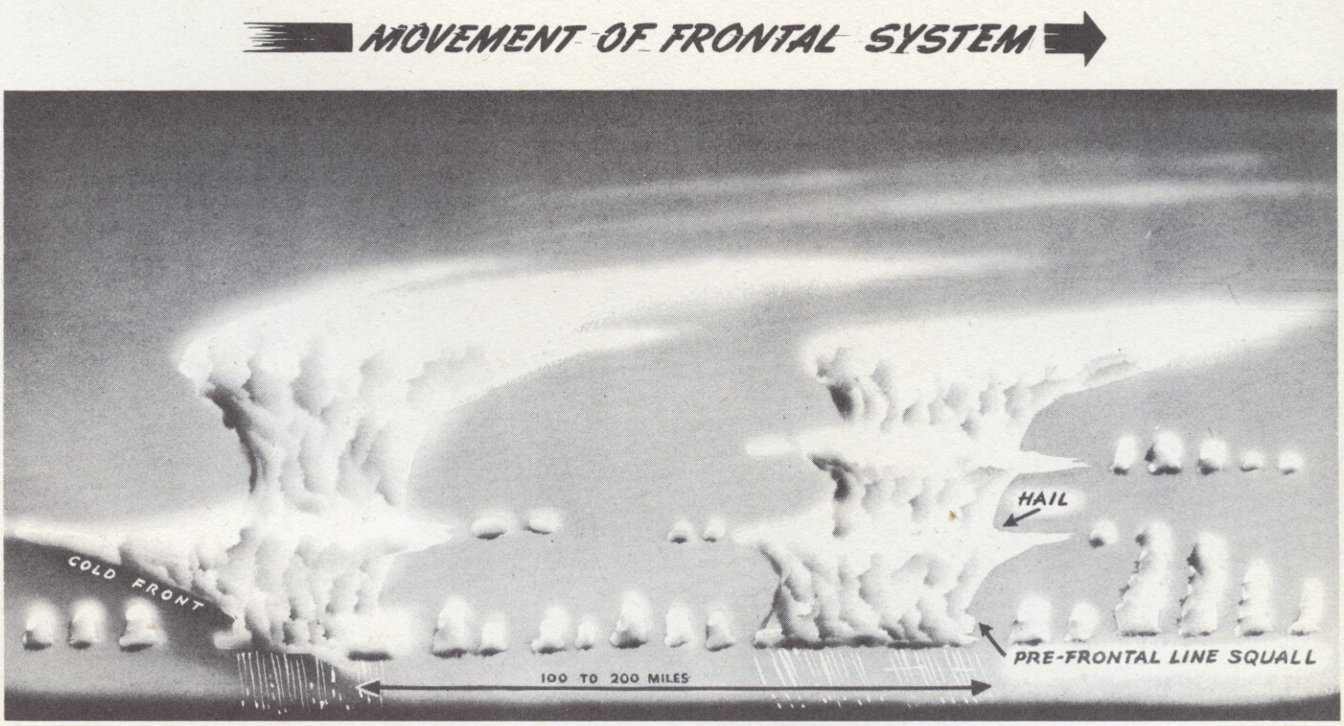
Section VIII

COLD FRONTS

In undertaking flight through a cold front, a pilot must use all his weather knowledge, his flying experience, and the services of an experienced forecaster. He may be forced to change his plans in flight, and the choice of alternatives will depend upon his own good judgement.

A moderate or severe front frequently presents every weather element hazardous to flight; and practically all common weather elements will be found at some position or altitude in the front. The weather can vary greatly from the simple ideal picture, and this may be responsible for the common opinion that no front quite conforms to the weatherman's description of it.

Fronts, like all other weather conditions, have definite life cycles and accordingly, do not retain their momentary characteristics. The life history of a front may be divided into phases, and within each phase the various weather elements will change in both type and intensity. Hence, in planning a flight a pilot must consider not only the position or intensity of the front at the moment, but also its past history,



Cross section through a cold front and prefrontal squall line.

its tendency to intensify or decay, the effect of terrain upon it, etc. This information can be obtained only from a series of weather maps, with the advice of a forecaster who has been following the frontal activity and is familiar with the characteristics of fronts in the region under consideration.

WHAT MAKES A FRONT

Fronts are classified according to whether a cold air mass is displacing a warm one or vice versa. The principal fronts are:

Cold front: A front along which cold air is displacing warmer air.

Warm front: A front along which warm air is displacing colder air.

It will be noted that the air masses are identified only as warm or cold in classifying the front. Other air mass properties determine the type and intensity of weather along the front.

Air motion along a front is not always upward in the warm air mass and downward in the cold. Activity along a front is the result of many factors, such as ground temperature difference across the front, the stability of the air masses, the terrain, the rate of pressure changes, etc. The intensity of a front cannot be determined by cursory examination of a forecast or weather map. The influence of each factor must be considered, and each front must be studied as an individual phenomenon according to the factors in operation at the time over the terrain of your flight.

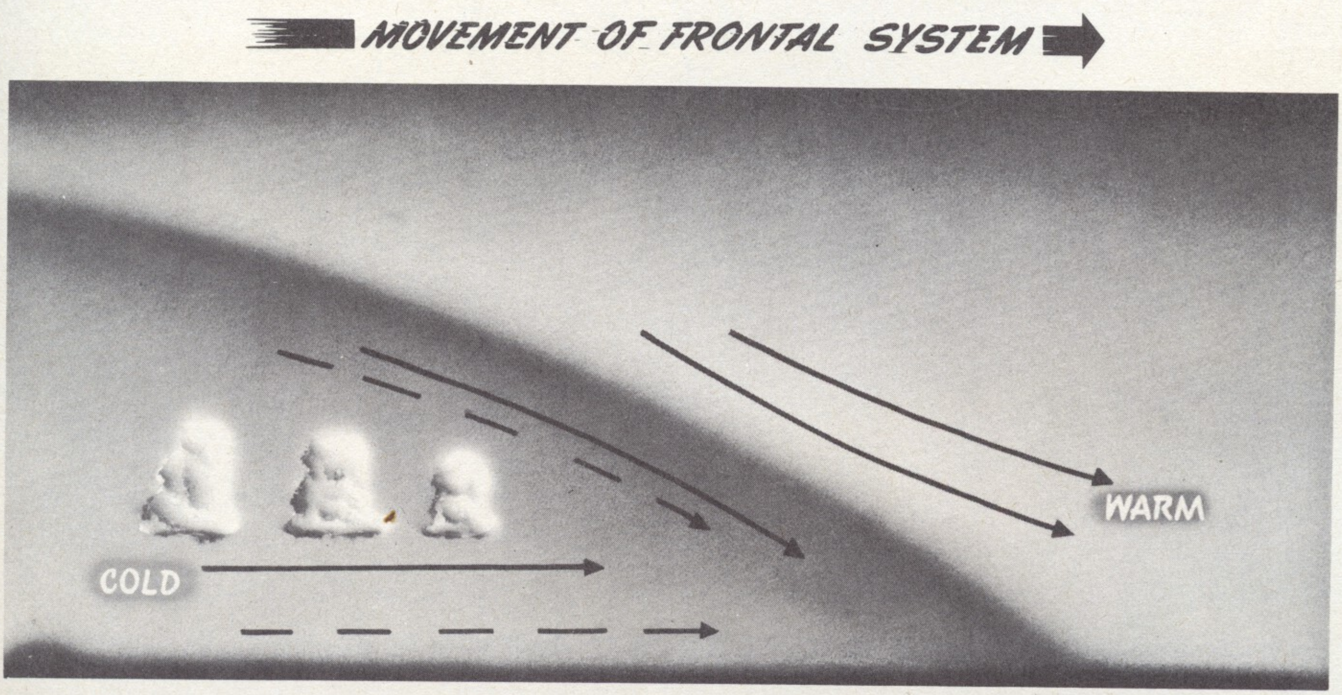
TYPES OF COLD FRONT

Along a cold front, the vertical motion of the air in each air mass, whether upward or downward, will have a definite influence upon the type of cloud formation and weather. The motions may be both ascending, or both descending, or any combination of the two; however, upward motion in the cold air combined with downward motion in the warm air can occur only when a front encounters the disturbing influence of a mountain barrier. It is obvious in any case that the heavier cold air will tend to underrun the warm air, and the front as a whole will slope toward the center of the cold air mass.

DRY FRONTS SHOULD BE FLOWN HIGH

When the air is descending in both the warm and the cold air masses, it is evident that condensation cannot occur within them and that any clouds present will be dissipated. Such a front is termed a dry, cold front.

The descending air in the forward portion of the cold air mass will, however, bring down with it the high-wind velocity of the air aloft; and this type of front is marked by strong gusty winds at the ground. Such fronts produce duststorms over dry terrain and are usually very turbulent.



The cold front. - With air descending in both air masses, the front is characterized by absence of clouds but with strong, gusty winds.

To a pilot this latter factor is important, since turbulent air is a potential hazard to flight. He must never be lulled into a false sense of security simply because no clouds or precipitation are associated with the front. The element of surprise in suddenly hitting extremely turbulent air along a dry front contributes to the possible danger.

Dry fronts should be flown at a high altitude, above 5,000 feet at least. At the first sign of turbulence, the speed of the plane should be reduced to 50 percent above stalling speed, and the usual sharp "bump" as the frontal surface is crossed, should be anticipated. Since the air is descending on both sides of the front, the plane will slowly lose altitude unless held in a gradual climb.

In the cold air mass, the region of descending air is restricted to a narrow band behind the front, and farther to the rear the air flows horizontally. A secondary front may form between the sinking air, which is being heated by compression, and the horizontally flowing air behind it. The secondary front thus formed may eventually become the predominant front.

The activity of a secondary cold front depends upon the moisture content of the air and the temperature difference between it and the ground. If the ground is the warmer, the forward portion of the cold air will tend to become unstable and the development of squalls is possible. When conditions are favorable, these squalls may develop into well-defined thunderstorms which further complicate the flight problem.

STUDY WEATHER MAPS AND SEE THE FORECASTER

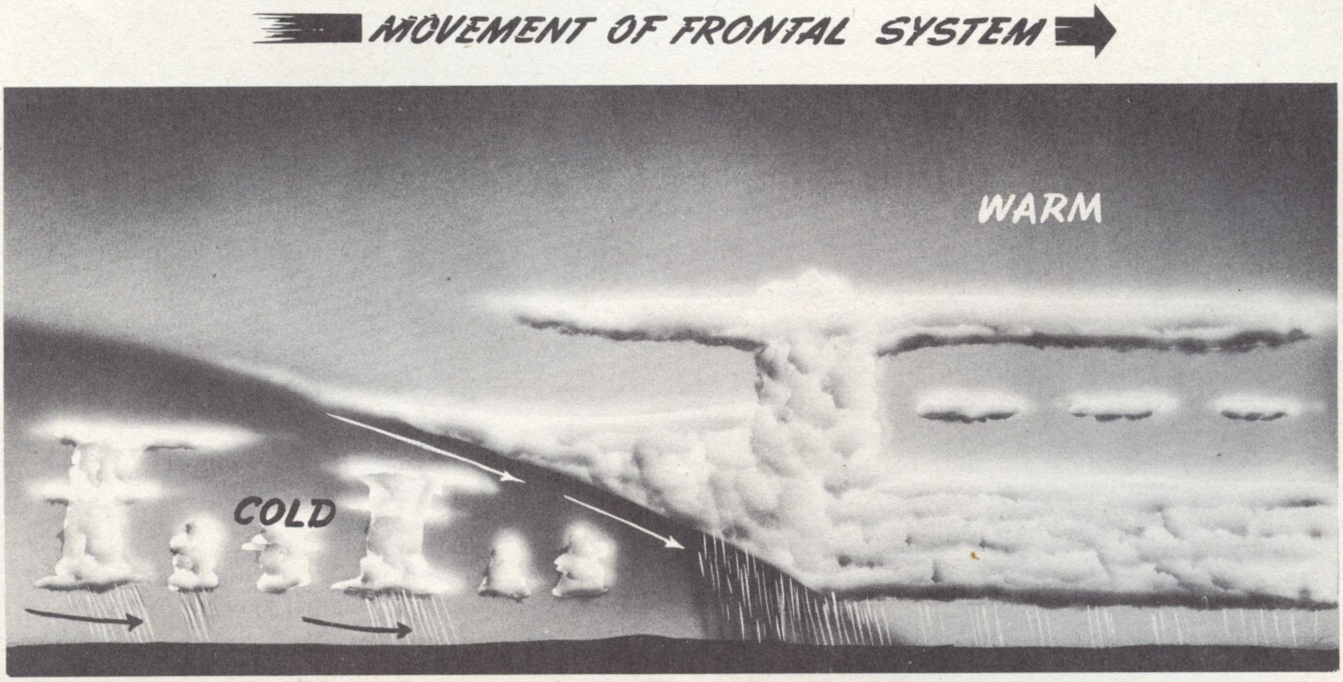
The intensity of ice accretion found in secondary cold fronts of this type will depend upon the moisture content and the degree of instability in the cold air. This is further reason for the pilot to consult the weather map and the forecaster, before undertaking flight through the region where a secondary cold front may develop.

Cold fronts with descending air in both air masses usually degenerate, particularly during the day. During the night, however, such fronts tend to become revitalized and the following morning may find them again active. Hence, the history of a front must be followed, and past weather maps as well as the current may should be used in forecasting conditions.

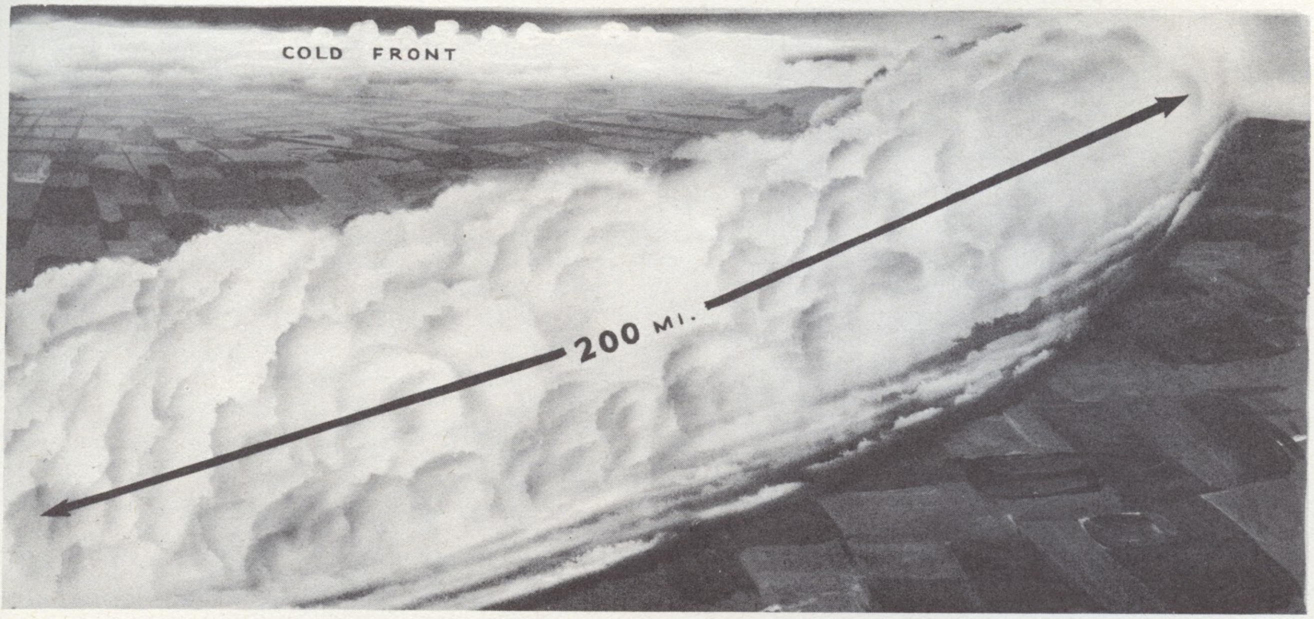
A COMMON TYPE OF COLD FRONT

The weather along a cold front where the warm air is ascending and the cold air sinking depends largely upon the stability of the warm air.

If the warm air is stable, cloud types within it will be stratiform. One or more cloud decks with fairly level bases will extend along the cold front. With continued lifting of the warm air, the upper portion of the cloud mass will reach the ice-crystal level and continuous light precipitation will develop.



The cold front. - With air in the cold mass having an unstable lapse rate, and in the warm mass having a stable lapse rate, squalls will develop in the cold air, and the clouds in the warm sector will be stratified. Secondary fronts generally develop with these conditions.



The line squall or prefrontal thunderstorm is characterized by the horizontal continuity of form. If you cannot fly over the top - fly just above the roll cloud if terrain permits and be prepared for extreme turbulence.

When the warm air is stable, the rising motion within it is gentle and steady. Even the added energy coming from the release of latent heat when condensation occurs will not develop any serious degree of turbulence. Therefore, relatively smooth flying is found in the warm air mass. Turbulence will be encountered close to the front.

Icing conditions in the stratiform or nimbostratus clouds along this type of front are usually light, particularly if care is taken in selecting a good flight path. Since the clouds are in layers, flight may be made most of the way between layers, where liquid water, except for regions of falling rain, can be avoided.

FLY BELOW THE FREEZING LEVEL

The altitude of the freezing level is important. If the warm air is of tropical origin, the freezing level will be high and the pilot can easily find a flight level where the temperature is above freezing. In the cold air mass, since the air is descending, the formation of cloud will be restricted to local cumulus near the ground, which should be avoided when the temperature is below 0^{o}C.

When the warm air is unstable, or the entire lower layers will be made unstable by lifting, the cold front takes on its most intense form, producing severe thunderstorms along the front or in advance of it (prefrontal).

Prefrontal thunderstorms usually reduce the intensity of storms along the cold front. Since the warm air between the prefrontal squall line and the front is usually sinking, the front will be the type first discussed. Such a front can best be crossed by going between the squalls or thunderstorms where, except for moderate turbulence, no serious weather conditions will be encountered.

When the warm air mass is conditionally stable, and no prefrontal squall line develops, thunderstorm activity will be confined to the frontal zone. The intensity of the storms may be forecast by studying upper air data or by reviewing the history of the front. The following hints, while not always applicable, will help in estimating the intensity of activity along such fronts.

HINTS ON ESTIMATING COLD FRONTS

The intensity increases as a front moves into warmer areas or where the warm air is more moist.

The greater the wind shear between the warm air and the cold, the more intense the activity.

The steeper the cold front, the more intense the activity, but the shorter the period of frontal passage.

If cold front thunderstorms are active in the early morning, the front will usually be severe, with a sharp wind shift and heavy rain. Such a front will not deteriorate during the day, other conditions being equal.

A SPECIAL CASE

Rising air on the cold side of a front and descending air on the warm side are only possible when the front crosses a mountain barrier. As a cold front approaches a mountain barrier, rising of the warm air mass is first accentuated. This intensifies the activity within the warm air; therefore, over and to windward of such a barrier, the intensity of thunderstorms is increased. As the cold front reaches the crest of the mountains, the warm air will flow down the leeward side and clouds within it will dissipate; at the same time, the cold air will be forced upward over the mountain barrier, further lifting the warm air remaining at high levels above it.

EXPECT SHOWERS ON WINDWARD SIDE

Showers may, therefore, continue on the windward side of the mountain. Even after the warm air has all been displaced and forced beyond the mountains, the cold air will continue rising. Unless it is very dry, showers may continue on the windward side of the mountain barrier within the cold air for many hours after the front has passed. This type of weather is common, particularly in winter, on the western slope of the Allegheny Mountains. Snow and rain squalls frequently persist over Ohio, western Pennsylvania, and the states southwest of this area, for many hours after a front has moved across the mountains.

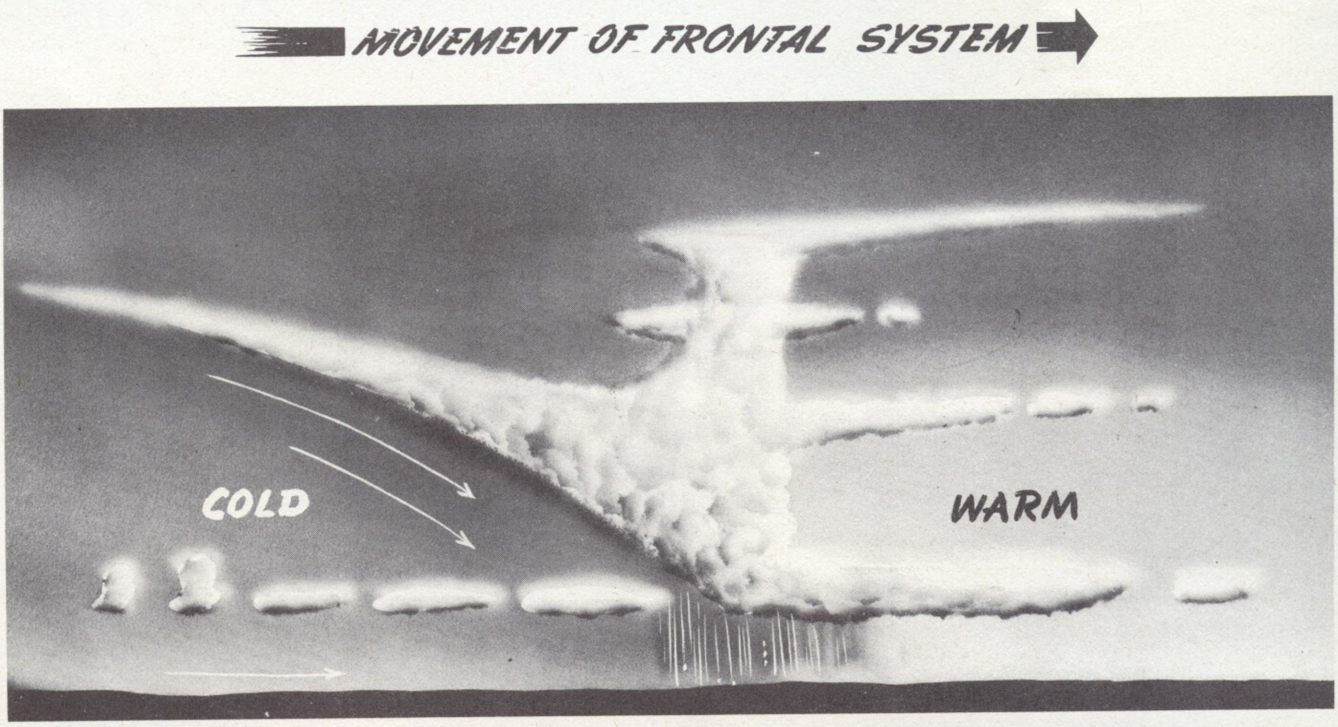
A cold, stable air mass always endeavors to flow around an obstruction, rather than over it. Therefore, cold fronts are usually retarded upon encountering mountains, though they may move unchecked around either end of a mountain barrier. Backed up against mountains, a front may become nearly stationary for a while. The horizontal extent of the associated weather will then increase and cloud forms will change from unstable to stable types. Thunderstorms and squalls will give way to an extensive overcast with continuous or intermittent precipitation. The cloud's structure will become stratified and the turbulence will decrease.

WHAT TO DO ABOUT IT

In planning a flight through a cold front the following points should be checked:

1. How fast is the front moving? Estimate by wind velocity at the ground, by projecting past movement, or ask the forecaster to compute the movement.

2. Are there indications of the formation of a secondary cold front? A region devoid of clouds



The cold front. - With air in the cold mass having a stable lapse rate, and in the warm mass with a conditionally unstable lapse rate, stratified clouds will form in the cold air and the frontal thunderstorms in the warm air mass will be close to the front.

for some distance behind the front, followed by a broken or overcast sky with low clouds, will indicate such a development. Squalls in the forward portion of the following cloud area are an almost certain indication.

3. What is the stability of cold air? Stable air produces stratiform clouds, unstable air produces cumuliform clouds.

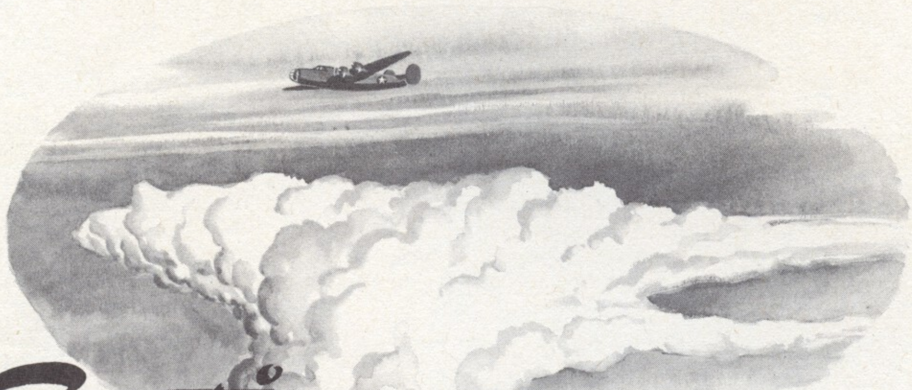
4. What is the altitude of the freezing level? Ask the forecaster, or refer to upper air observations or pilot reports.

5. What is the stability of warm air? Stable air will produce stratiform clouds - if sufficient moisture is present, nimbostratus. Unstable air will produce cumuliform clouds - if sufficient moisture is present, cumulonimbus.

6. Are there indications that a prefrontal squall line will develop? Refer to the section on prefrontal thunderstorms in section VII.

7. If flight through the front must be made, where will the front be met? Will you change altitude on passing from one air mass into the other? Will you fly contact, on instruments, or over the top?

A cold front may possess any degree of intensity. An experienced pilot will encounter various degrees, but one thing is certain. If he has ever crossed a severe front, he will be on his guard. He will, in every case, carefully study the factors listed above and will proceed with caution.



Section IX WARM FRONTS

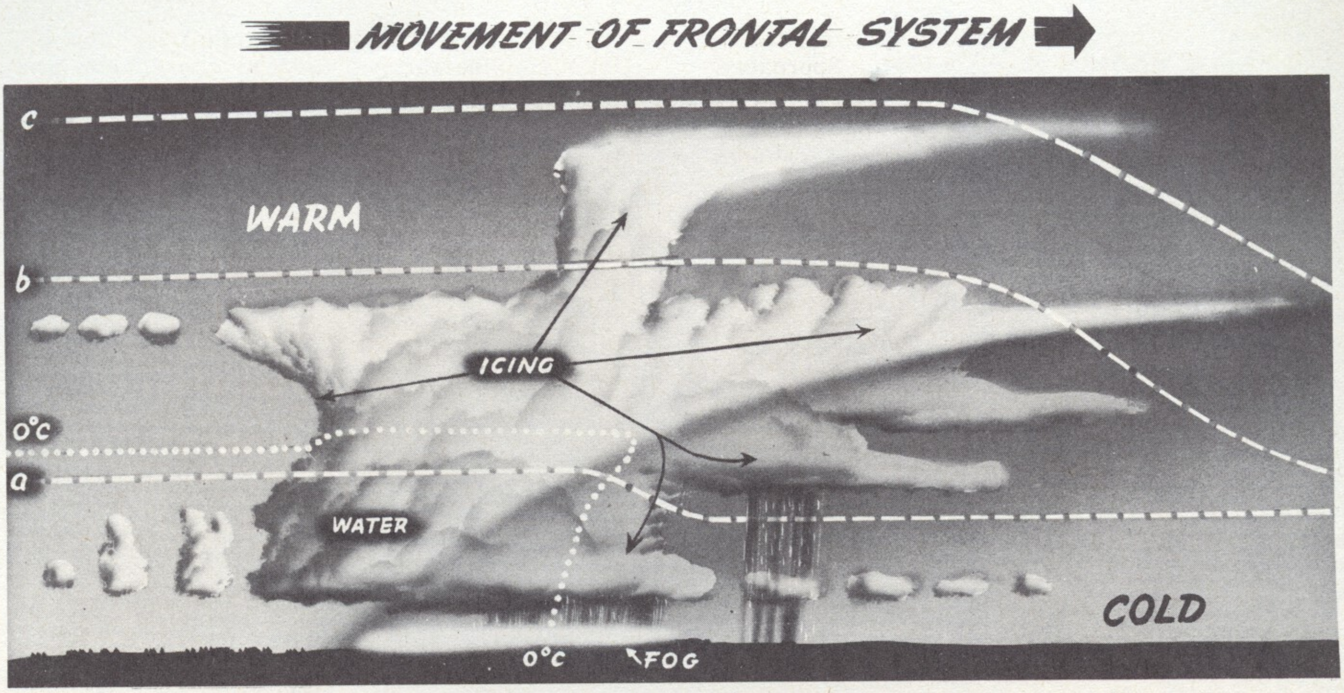
The type of weather associated with both warm fronts and cold fronts is governed by the same factors; that is, the stability and vertical motion of the two air masses involved. Therefore, the paths to be followed when flying through a warm front can be tentatively decided upon before take-off if the pilot follows the same rules, and changes in flight plan will depend upon the pilot's observation of actual conditions. The vertical motion of the air masses is of two types; both air masses ascending, or both descending. Although descending air occasionally occurs along upper warm fronts, it is rare at the surface. Therefore, warm front activity of any consequence generally results from ascending air in both air masses.

The activity along a typical warm front develops from the lifting of the warmer air mass to its condensation level as it flows upward over the obstructing wedge of cold air. Eventually, as the upward flow continues, the clouds thus formed pass the ice-crystal level and precipitation occurs. The intensity and extent of warm front activity will depend upon the slope of the front, the stability of the air masses, the height of the condensation, freezing and ice crystal-levels, and the speed with which the warm air flows up the front.

CLOUD CHARACTERISTICS

Because warm air generally has a high moisture content, the clouds first forming within it over the front will be dense. The severity of icing conditions and turbulence will be determined by the instability of the warm air, and the location of icing regions by the height of the freezing level. These two factors, the stability of the warm air, and the height of the freezing level, are important, especially if the front has previously shown only limited activity. Absence of activity does not necessarily mean that the warm air is stable; it may be conditionally very unstable, and ready to produce extensive thunderstorm activity as soon as the lifting progresses far enough.

The cold air mass ahead of a warm front may always be considered stable, since it is overrun by warmer air. Even though its lapse rate indicates instability, vertical motions will be limited and clouds within the cold air will be of the stable type - stratus and altostratus.



The warm front. - This all-inclusive idealistic cross section illustrates three recommended flight paths to avoid prolonged icing: (a) At an intermediate level on instruments; (b) Over the top, but on instruments at times; (c) Over the top, clearing all clouds.

OKAY ABOVE OR BELOW

Flight through the cold air mass may, therefore, be made above or below the stratiform clouds. Except in passing through a cloud layer or a heavy shower, there is little possibility of icing or turbulence.

If the warm air is conditionally unstable, the clouds above the warm front will be cumulonimbus. Precipitation will be widespread and the cloudiness extensive, reaching from the ground position of the warm front to a point high above the cold air mass. Cloudiness will frequently be broken, permitting occasional glimpses of the ground.

FROM WARM TO COLD

When the warm air is conditionally unstable, a cross section through the front will show the following sequence of weather types progressing from the warm toward the cold air:

Over the lower portion of the front there will be cumulonimbus, with moderate to occasionally heavy showers. If the air is of recent tropical origin, the freezing level will be high, seldom under 10,000 feet except in winter. The base of the clouds is relatively low where the cold air is shallow.

In the cold air just below the frontal surface, nimbostratus clouds prevail. If the cold air mass is stable and precipitation has been prolonged, these clouds may build downward to the ground as a form of fog (prewarm-front fog). Occasional showers or intermittent drizzle will ordinarily be found under the lower portion of the front with such conditions.

Farther up the front, the ceiling increases and the low clouds give way, leaving the deck of clouds lying along the frontal surface at an intermediate level. The visibility beneath this cloud deck will be fair and, except for an occasional shower or snow flurry, the weather will be good.

Still farther up the front a point is reached where the warm air becomes extremely unstable because of the amount of lifting to which it has been subjected. This region, usually 200 to 300 miles ahead of the front, is characterized by high level thunderstorms, showers, or light continuous rain. Its position and extent will depend upon the slope of the front. However, since the weather in this region originates in the overrunning air several thousand feet above the ground, any clouds in the cold air will be caused by falling precipitation and will, therefore, be stratified, ragged, and not dense.

PROBABLE FLIGHT CONDITIONS

Severe icing conditions generally occur in connection with warm fronts, since all the elements favorable to intense ice accretion exist. The cloud masses contain large quantities of suspended liquid water, vertical lifting of the air occurs, and the cloud mass is thick and widespread.

In flying through a warm front from the warm to the cold air without changing altitude, the pilot will encounter a rapid drop in temperature. This drop is frequently in excess of 10°C. While the freezing level in the warm air may be 6,000 or 8,000 feet, it may be at ground level a short distance ahead of the front. Therefore, the icing danger in the warm air mass is limited to high levels; but it exists at all levels where clouds or rain occur in the cold air mass. This is particularly true in winter when the warm air is conditionally unstable and nimbostratus clouds prevail along the front. The most intense icing conditions will usually be found where frontal activity is just starting or is increasing. In a region where precipitation has been heavy for some time, the clouds will have lost much of their suspended liquid water.

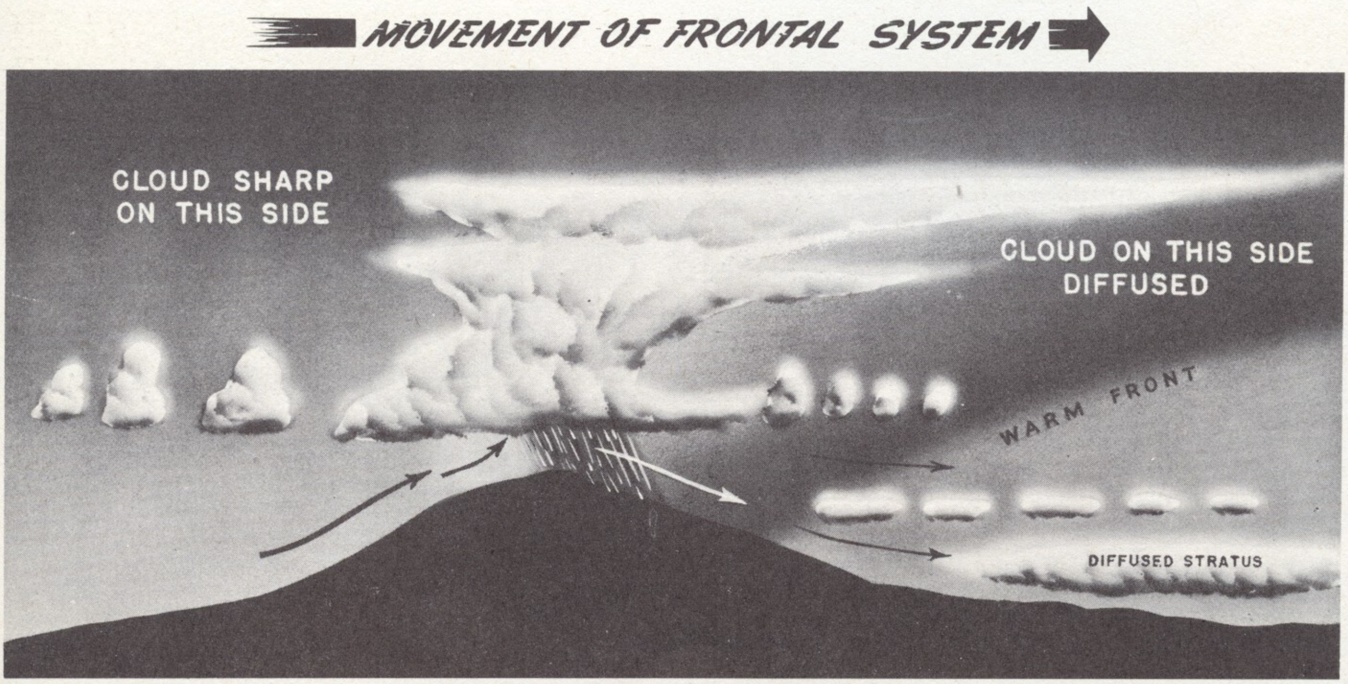
TEMPERATURE DICTATES FLIGHT PATH

The selection of a flight path under such conditions should be based upon the temperature distribution at the time. This information can be obtained from the reports of other flights, radiosonde (RAOB) data, or by careful calculation. If the temperature is below freezing at all levels and the cloud mass is continuous, moderate icing must be expected. The only safe flight path is then at high levels where all clouds may be avoided or those encountered will be very cold and composed mostly of ice crystals.

If when flying from the cold toward the warm air, a fairly close approach can be made to the warm front under the altostratus deck before the nimbostratus cloud mass is encountered, it will frequently be possible to fly through clear air to a point where the front can be crossed immediately into above-freezing temperatures in the warm air. Transit through the icing zone can then be made quickly. De-icing equipment should be placed in operation and the front crossed, if possible, at right angles and at an altitude where the temperature in the warm air mass is known to be above freezing.

When flying through the front from the warm towards the cold air, the pilot should make his flight just below the freezing level in the warm air, crossing the front at right angles with the de-icers operating, and maintaining the same altitude until clear air is found. If clear air is not found shortly after passing through the front, it may be sought by ascending or descending slightly.

When a warm front approaches a mountain barrier, the slope of the front usually steepens to conform to the mountain slope. Steepening of the front intensifies the vertical lift of the warm air, and the clouds will build to a higher altitude. The lower portion of the cold wedge, trapped against the mountain barrier, soon becomes saturated and filled with cloud, with extremely low ceilings prevailing. However, on the leeward side of the mountains, downward flow of the air tends to dissipate the clouds; and if the front can be crossed at that moment the risk of icing will be reduced.



On crossing a mountain barrier, the warm front weather is generally separated from the warm front, except stratified clouds persist in the cold air mass.

WIND VELOCITY MAY DOUBLE

The effect of a mountain barrier is not confined to intensifying the activity of a warm front. Wind velocity increases above the mountains, and at high levels the velocity may double. Thus in crossing a range of mountains against the wind, caution should be exercised. Avoid descending until a definite fix is established and it is certain that the flight path will avoid all obstructions.

Temperature is not a sufficient guide in helping one decide when to let down after crossing mountains, particularly when the warm front is near the crest. Down-slope flow of the air on the lee side of a mountain may warm it sufficiently to make the pilot think he has crossed the front when actually the mountains are still ahead of him.

THE CASE OF STABLE WARM AIR

When the warm air is stable, the clouds along a warm front will be stratiform. This does not mean, however, that layers will not merge. Throughout the nimbostratus along the front, the cloud mass will generally be very deep.

The sequence of clouds encountered when going from the warm to the cold air mass will usually be nimbostratus, altostratus or altocumulus, cirrostratus, and cirrus. Except for the nimbostratus, all are high clouds.

If the warm air mass is relatively dry, it will flow for some distance up to the front before clouds form within it, and the zone of clouds may, therefore, be a 100 miles or more in advance of the surface front. Low clouds may be encountered in the cold air if rain falls from the warm air above, but they will be stratified and shallow. Icing will be a hazard only at upper levels. This permits contact flight or else flight between layers through the front.

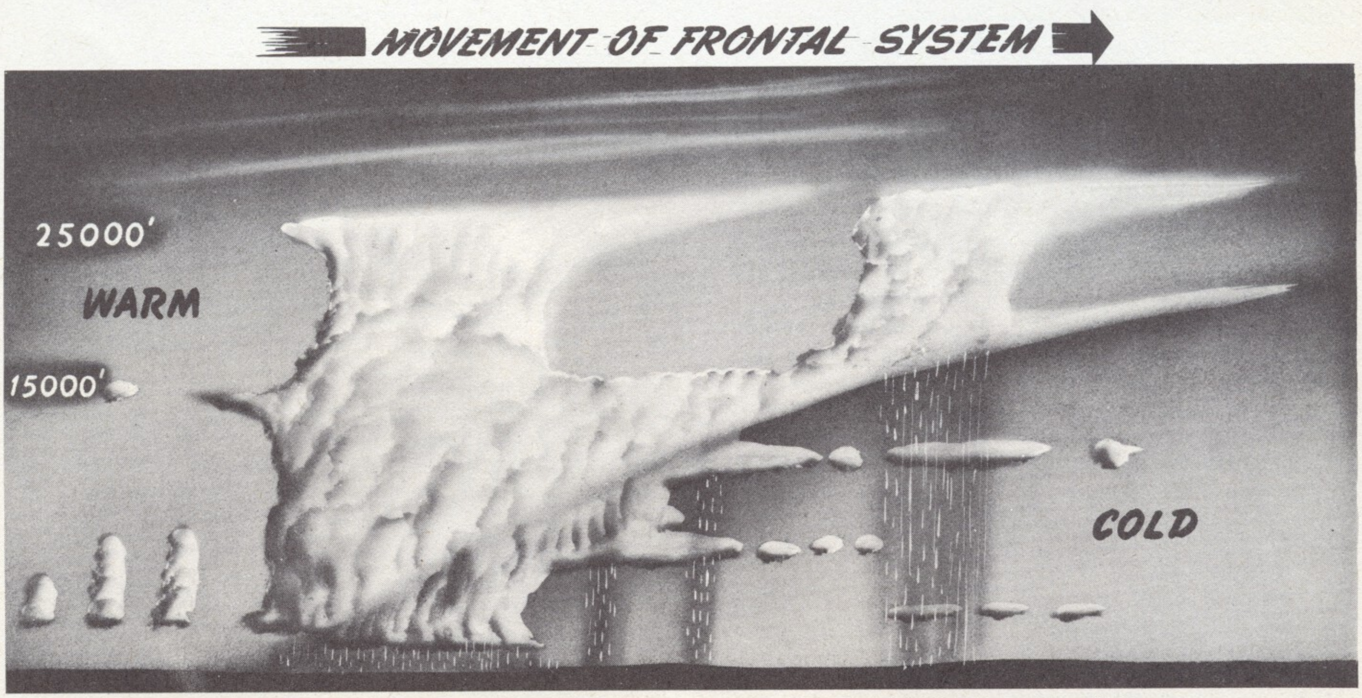
FLIGHT ON TOP USUALLY POSSIBLE

When the warm air is stable, precipitation is generally restricted to the region of the nimbostratus cloud mass. The top of the cloud mass is considerably lower than when the air is unstable, and flight on top is frequently possible.

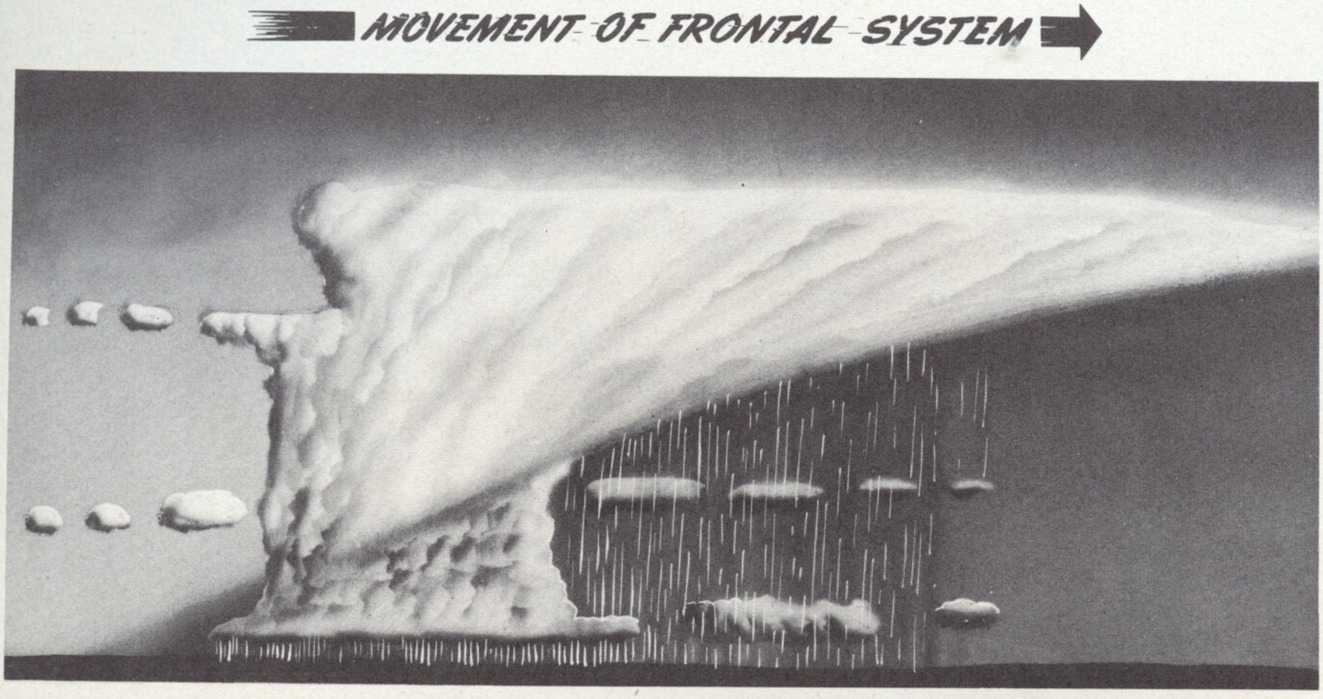
Fly with caution where stratiform clouds prevail. If any layer of air becomes unstable, dense cloud may quickly be produced which will be an icing hazard in freezing temperatures. Therefore, whenever the temperature is below freezing, flight should be made between layers or on top, entering the clouds only when necessary to change altitude.

MOVEMENTS AND CHARACTERISTICS

In estimating the weather, it is important to consider the slope of the front and the depth of the cold air. During the summer months, particularly in southern latitudes, the cold air may not be deep



Warm front weather occurring with a conditionally unstable lapse rate. High level showers or thunderstorms well in advance of the front commonly occur with such conditions. The thunderstorms tend to be scattered at random ahead of the front.



Warm front weather associated with a very moist, conditionally unstable warm air mass. This is the heavy precipitation producer. Icing is moderate to severe at all levels above the freezing isotherm, because of the dense, unstable cloud mass. There is an almost unbroken line of thunderstorms of deep extent ahead of the front.

enough to lift the warm air above its condensation level. The cloudy area will then be extensive, with low ceilings but little precipitation. During the day the clouds may become broken, but after dark they tend to close in again and lower, and the pilot may find most terminals in the area closed.

A warm front ordinarily moves more slowly than a cold front; and, because it is passing over colder ground that is usually wet from rain, the warm air mass will be cooled from below in the region behind the front. This encourages the formation of stratus clouds in the warm moist air mass and sometimes makes it difficult to recognize the true position of the warm front. Failure to identify the front correctly is responsible for many inconsistent reports of warm front movement.

PLAN ON LOW CLOUDS

Extensive areas of low cloudiness are usually associated with slow moving warm fronts. Warm fronts usually move more slowly at night. If a flight must be made to a terminal near a warm front, the occurrence of low clouds should be anticipated.

Once a warm front stagnates it seldom regenerates. Ordinarily the front dissipates gradually. It again becomes active only if warmer or less stable air moves over it. The location of the new activity may or may not coincide with the position of the decaying front, depending upon the balance of the various elements involved at the moment.

The major hazards to flight through a warm front are ice accretion and low ceiling. A satisfactory flight plan can be made only when the limits of the regions occupied by these hazards are known.

Section X
THE OCCLUSION

When a cold front overtakes a warm front and the air mass in the warm sector is lifted aloft and cut off from the ground by the meeting of the two cold air masses, the two fronts are said to have occluded. The combined frontal system is called an occluded front or, simply, an occlusion. Since a cold front overtakes a warm front first at the center of a cyclone and progressively further away from the center, occluded fronts normally characterize only mature cyclonic systems.

Three air masses are always involved in the occlusion process; the cold air mass behind the cold front, the warm air mass occupying the warm sector, and the cold air mass in advance of the warm front. When the warm air in the trough aloft can no longer be identified, the system becomes either a cold or a warm front depending upon whether the first or the second cold air mass was the colder.

When the air mass behind the cold front is the colder and more dense, it will underrun both the warm and the cold air masses ahead of it. The occlusion is then called a cold-type occlusion. When the air mass in advance of the warm front is the colder and more dense, the cold air mass in the rear will underrun the warm air mass, but will be forced to rise over the still colder air in advance. The resulting system is then called a warm-type occlusion, since the front formed between the two cold air masses is a warm front.

WATCH FOR SAME GOVERNING FACTORS

During the formation of an occlusion, weather conditions along the frontal surfaces will be determined by the same factors which govern warm and cold front weather separately; that is, the stability of the individual air masses, the rapidity with which each air mass is rising or sinking, and the rate at which the various fronts move. There will be other contributing factors, such as variations in terrain, wind velocity, etc.

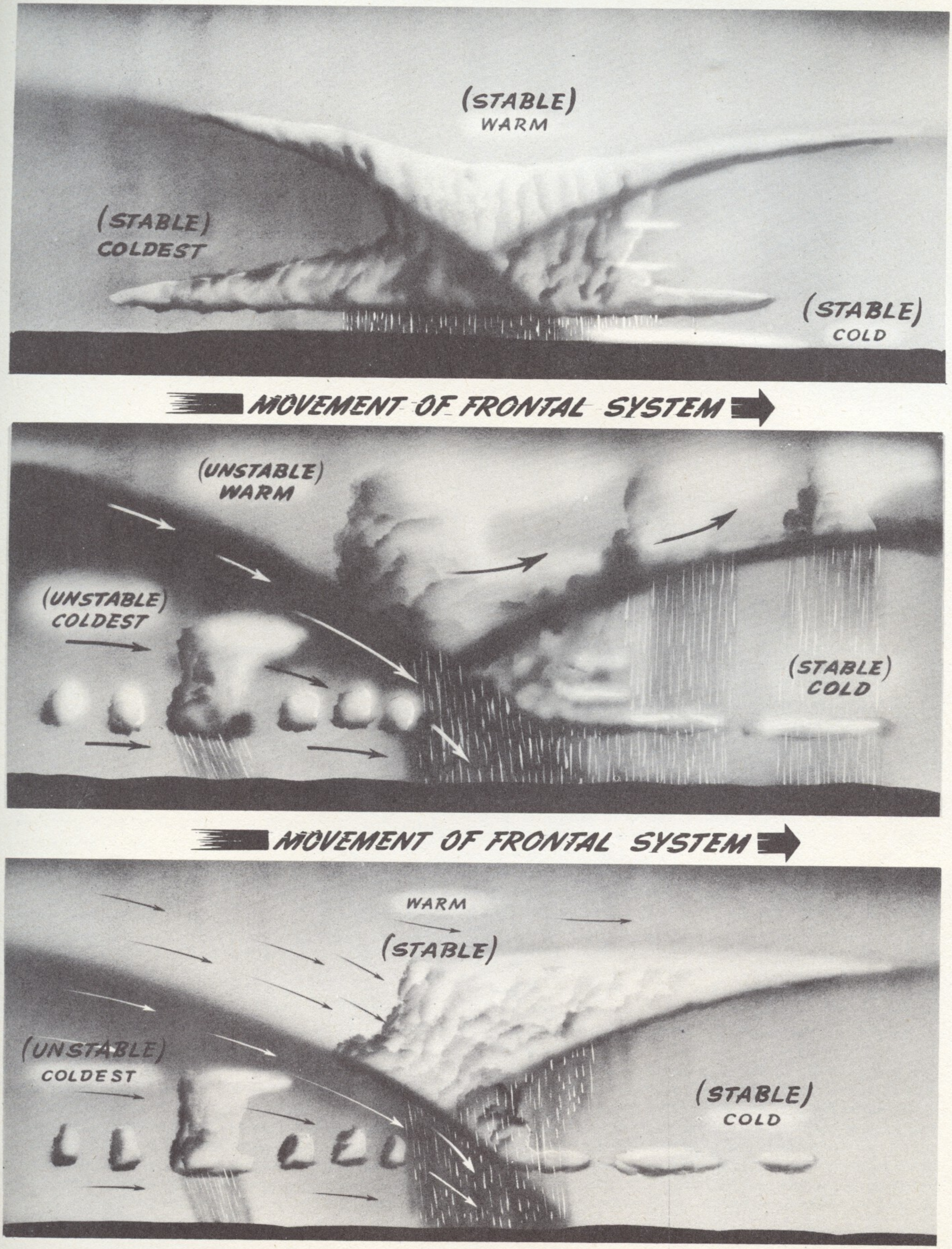
TIME AND DISTANCE ALL IMPORTANT

In analyzing occlusions, the factors of time and distance are important. Since the occlusion is a progressive development, its character changes with time. As the warm air is lifted to higher levels, the slope of the frontal surfaces diminishes and the weather activity also diminishes. In the following examples each type will be described at the time when its activity is most pronounced. This should be borne in mind when actual situations are encountered. The importance of considering the effect of age on an occluded front when planning a flight cannot be stressed too greatly. Age will generally determine whether the air masses are stable or unstable, a condition which further determines the form of the clouds and the type and intensity of precipitation, turbulence, and icing.

As the occlusion develops outward from the center of the low, the most active weather will usually be found at the outer end of the occlusion. The presence of an occlusion normally indicates that the low-pressure system is beginning to stagnate. The deterioration of the storm may proceed rapidly or slowly, depending upon various controlling factors. As the low-pressure area fills, the wind velocity decreases and weather activity along the occluded front degenerates.

EXAMPLES OF OCCLUDED SYSTEMS

The following typical examples of occluded systems should be studied carefully. The freezing level has not been indicated on the diagrams because its position will vary with the season and with the history of the individual air masses. With the freezing level in various positions, many different combinations of icing zones are possible. The correct choice of a flight path depends on a thorough understanding of the complicated structure of occluded fronts.


(STABLE)
WARM
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COLDEST
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MOVEMENT OF FRONTAL SYSTEM
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(STABLE)
COLD
MOVEMENT OF FRONTAL SYSTEM
WARM
(STABLE)
(UNSTABLE)
COLDEST
(STABLE)
COLD

COLD-TYPE OCCLUSION

This type of occlusion occurs when a low-pressure area stagnates well away from the geographical regions where fronts tend to form. The horizontal motion of the frontal system is usually slow. Winds are light and turbulence is weak.

This type produces extensive areas of low ceiling, poor visibility, and if the freezing level is low, moderate icing. Precipitation will be light along the front, with light showers or drizzle elsewhere. If the temperature at the ground is below freezing, drizzle may be present as a definite hazard.

ABOVE 12,000 BEST

The most satisfactory flight path under such conditions is over the top, which is usually above 12,000 feet. Ascent or descent through the altostratus cloud layers along the frontal layers will not present a hazard.

When this type of system has prevailed for more than 24 hours, there is a tendency for the clouds to become stratiform through the frontal zone. Flight between layers may be made at intermediate altitudes. Such cloud forms will generally be found after continuous precipitation has stopped along that portion of the front which is to be crossed.

COLD-TYPE OCCLUSION

This type of occlusion is common over continents in summer, but is rarely found over oceans. Cumuliform clouds predominate in both the warm and the coldest air masses, with stratiform clouds in the cold air. Icing conditions will be encountered only in the upper portions of cumulonimbus clouds.

Locally low ceilings may occur in the cold air mass, but they are never extensive. At night, fog may form under the clouds, usually after the thunderstorms and showers have dissipated.

Secondary fronts may occasionally develop but they never assume the well-defined form which they have when the warm air mass is stable.

Flight through this type of front is best made at low levels below the base of the thunderstorms. Here the possibility of turbulence is small and the danger of icing negligible.

COLD-TYPE OCCLUSION

This type is common over the western parts of oceans in winter and over eastern parts of continents in summer. The cloud mass in the warm sector is usually dense and unbroken, producing continuous light precipitation. The top of the cloud mass is usually at about 15,000 feet. It is marked by moderate to severe icing conditions, but little turbulence. The low, unbroken ceiling of stratiform clouds will prevail in the cold air mass. Icing will be encountered here along the cold front if the freezing level is below the cloud base.

In the coldest air mass, which is conditionally unstable, the sinking motion near the front provides a zone of broken clouds. Behind the zone where the air is sinking, squalls or showers develop and may assume the characteristics of a secondary cold front.

TRY TO STAY ON TOP OF MOST WEATHER

The most satisfactory flight path is over the top of all weather. A quick descent through the altostratus clouds will not result in any serious icing. Flight at low levels is satisfactory if there are no obstructions and the freezing level is high. When temperatures are low, freezing rain will frequently be encountered in this region.

An alternative flight path is between layers above the tops of lower clouds. De-icers must be used in flying through the front, where cloud layers merge, if the temperature is below freezing.

COLD-TYPE OCCLUSION

This type of occlusion is frequently mistaken for an upper warm front because of the cumuliform clouds which precede the passage of the trough aloft and give it the characteristic of an upper warm front.

When the cold air in advance of the front at the ground is unstable, upward motion in it will produce a heavy cloud mass with its upper limit at the warm front surface. The clouds cannot go through this surface, for the cold air still remains heavier than the warm air above it.

If the cold air moves over ground warmed by the sun, it may become warm enough to mix with the air above. Clouds can then grow from the lower air mass into the upper one. This "break-through" will usually occur well ahead of the trough. The resulting weather is typical of an upper warm front, that is, instability showers, rising pressure, and a tendency for the clouds to become cumuliform near the front.

WATCH FOR SURPRISES

This "break-through" will usually come in the late afternoon and continue through the night, gradually diminishing in activity. Because previous reports will have indicated an unbroken level cloud top above the warm front, the sudden development of a solid bank of cumulonimbus clouds is most disconcerting.

WARM-TYPE OCCLUSION

This type of occlusion is common in winter over the eastern parts of oceans and the west coasts of continents in middle latitudes. The coldest air ahead of the system will contain only shallow low clouds or no clouds at all. Light rain will fall from the stratiform clouds in the warm front. Flight, contact or between layers in the cold air, presents no difficulties.

It usually moves slowly. Consequently low ceilings and visibilities in the coldest air mass will persist in a given area for a long time. Light rain or intermittent drizzle occurs ahead of the warm front, with showers or squalls in the unstable cold air mass.

If the flow of cold air strengthens, a secondary cold front may develop at point "A"; this front may eventually underrun the warm front and lift all air masses. This development is, therefore, capable of producing an upper front condition.

WATCH OUT FOR THE FRONT ALOFT

The real change of weather will occur with the first arrival of the cold air, when the ceiling will lower suddenly and the amount of rainfall increase as the heavy cloud mass in the unstable cold air comes into play. The cold air deepens rapidly and the heavy squalls or thunderstorms take place in the region where the cold air overruns the coldest air. If there are no complicating factors, such as mountains, the squalls will cease after the warm front passes at the ground, although low stratocumulus clouds may persist.

When this type of occlusion moves against a mountain range, as it often does in the northern coastal range in the northwestern United States and British Columbia, high ceilings and light rain generally precede the arrival of the cold front aloft. The front passage is followed, however, by heavy snow squalls, low ceilings, with severe turbulence and glaze icing conditions, often with strong shifting winds. These conditions persist until long after the front has passed.

EXTENSIVE FOG AREAS POSSIBLE

Since the instability of the cold air is partly due to heating at the ground, this type of front is the most active during the afternoon and evening, with the activity diminishing during the night. Ground fog may form in the cold air after midnight, if the wind is light. In conjunction with low ceilings and the possible fog in the coldest air ahead of the front, this may produce an extensive fog area. The stable air aloft is characterized by the stratiform clouds with a minimum of turbulence and rarely causes more than light icing. If temperatures near the ground are below freezing, freezing drizzle may occur.

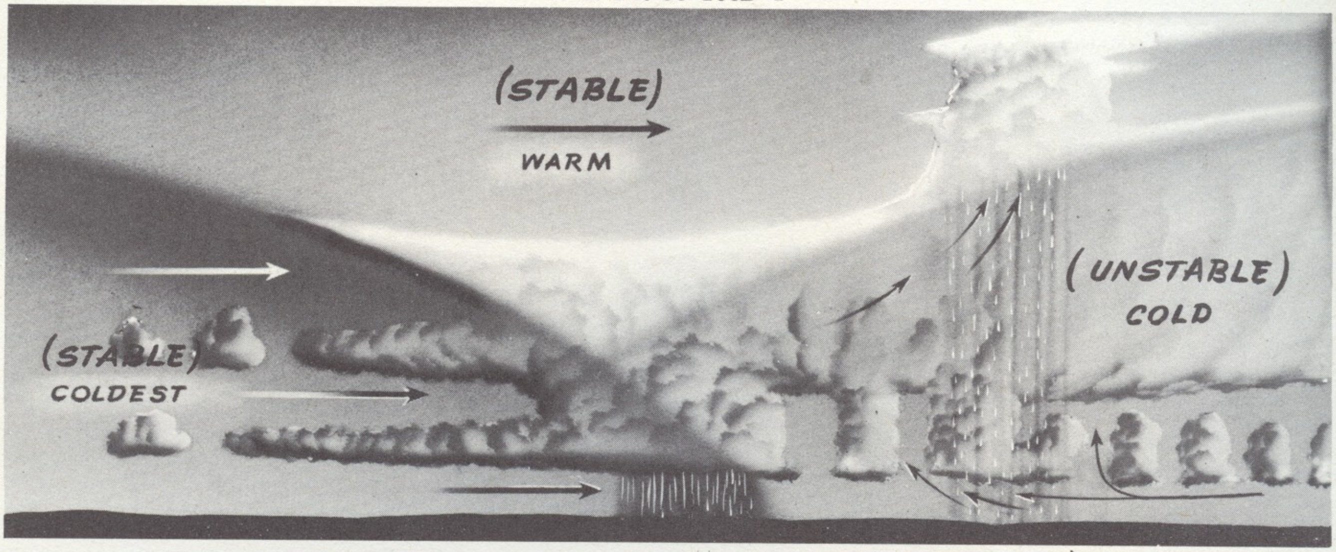
The best flight path is over the top. As a second choice, flight may be made above stratified clouds in the coldest air mass. After penetrating the front, the pilot can maintain contact flight by avoiding the squalls.

WARM-TYPE OCCLUSION

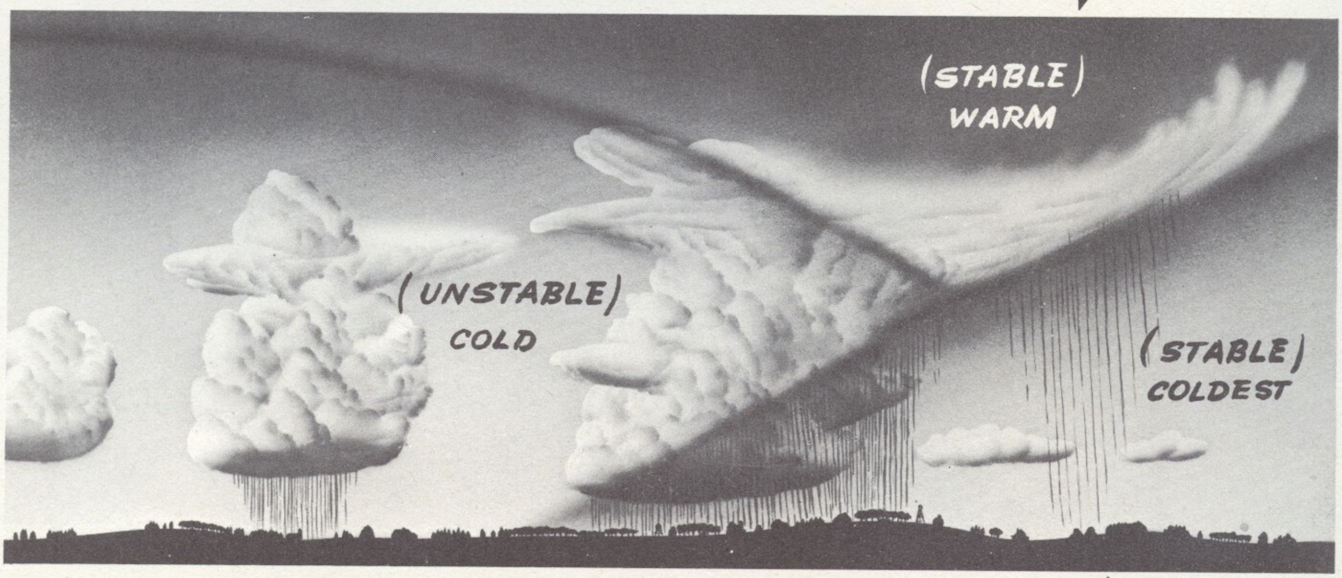
This type of occlusion is common over the interior of continents. It produces high level thunderstorms in summer and may produce light snow in winter. In the latter case, melting snow will cause a narrow band of stratiform clouds at low levels if the lower air is warm. Warm-type occlusions seldom persist when warm air mass is unstable. Usually the risk of thunderstorms is ended within 36 hours, unless the frontal system is revitalized by a surge of unstable air aloft.

AVOID CUMULONIMBUS CLOUDS

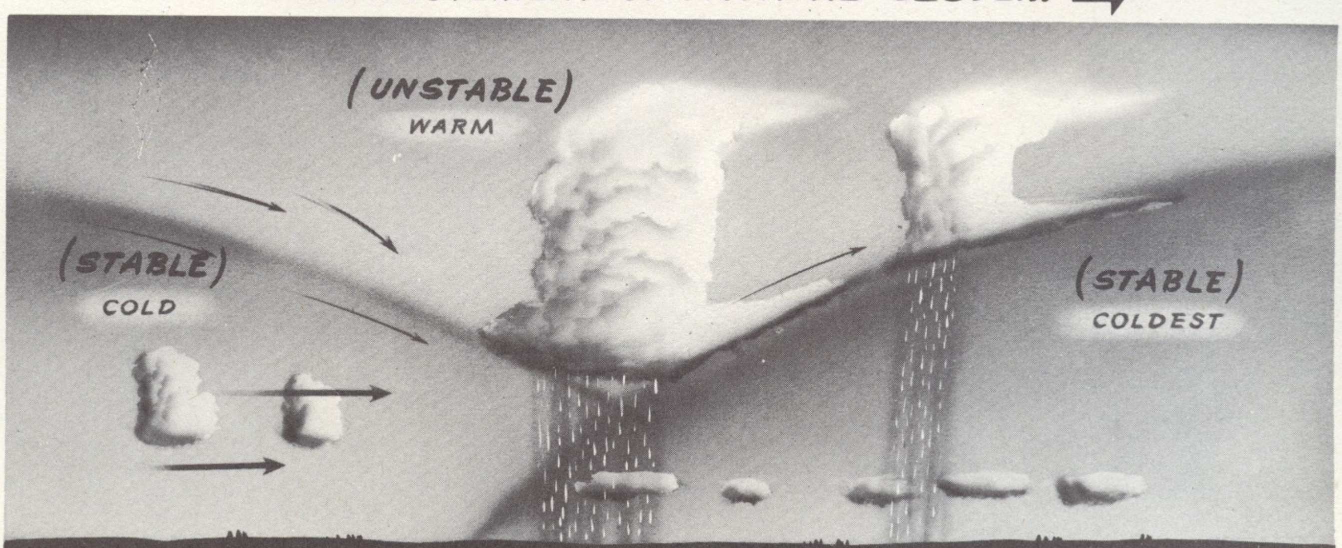
A flight path at low levels above the lowest stratiform clouds is recommended. At higher levels, the pilot should avoid the towering cumulonimbus clouds by flying over or around them.



MOVEMENT OF FRONTAL SYSTEM



MOVEMENT OF FRONTAL SYSTEM



Section XI

PLANNING THE FLIGHT

A well-planned flight is a successful flight.

The importance of this precept cannot be overemphasized. In military operations, an airplane which fails to reach its objective cannot contribute to the fulfillment of the mission. Even if it lands undamaged with its crew uninjured, the time, material, and training invested in the flight is for the moment wasted. Worse still, a great tactical loss may have been incurred through the absence of that particular aircraft on its assigned mission. It is, therefore, of primary importance for pilots to plan and conduct flights with absolute precision.

The most important factors in a flight plan are:

1. The course and distance to be flown.

2. The minimum safe altitude over the terrain.

3. The required fuel supply, including reserve.

4. The horizontal and vertical extent of weather conditions.

5. The wind velocity and direction at various levels.

6. Forecasted changes in winds and weather.

7. Flight path.

8. The alternate plan to be followed if a landing cannot be made at the destination.

9. The altimeter settings along the route and at the destination.

10. Cockpit check list to insure that the airplane and its equipment are operating properly.

Many of these factors are not directly concerned with weather, but if adverse weather conditions are met they may play an important part in the success of a flight. It is, therefore, proper that they should be considered in detail here.

As a rule, every pilot has some idea of these factors before he starts on a flight. However, if his ideas are not precise, or if the situation is not just what he thought it was, an emergency is in the making. An experienced pilot can often meet an emergency successfully by reason of long training. Experienced and inexperienced pilots alike, however, will do better to avoid emergencies entirely. An emergency is no emergency if you have planned to meet it. The perfect flight plan is one which plans for everything that might become an emergency.

The basic steps to be followed in planning any flight do not vary; the details of the steps will vary with the experience of the pilot and the nature of his mission. In the following analysis of the 10 factors listed above, the need for accuracy is stressed.

THE COURSE AND DISTANCE TO BE FLOWN

Necessity of knowing accurately the course and distance to be flown is obvious. Even in contact flight, the landmarks to be used as check points along the route, the time over each check point, and the estimated time of arrival at the destination should always be computed before departure. The check points and the course to be flown should be marked on the map. Unless this procedure is followed, valuable time will be lost and the pilot's attention distracted by searching the map for landmarks observed from the air.

LOCATE SPECIFIC LANDMARKS NOTED ON THE MAP: DON'T JUST COMPARE THE MAP WITH THE LANDSCAPE

When available, landmarks in the immediate vicinity of radio fixes should be chosen. If, because of cloud or fog, the position check must be made by radio, the precomputed estimates will still hold good and will permit the pilot to determine his gain or loss of time. This is particularly important when accurate data on the wind at the flying level are not available. A succession of fixes provides the only way of determining ground speed, and when the fuel supply is limited this becomes vital to the successful completion of the flight.

Regardless of the weather conditions, the compass course and heading to be flown should be calculated. The course should be marked on the map, together with a reciprocal course, and during flight the compass heading should be frequently checked against the available landmarks. Confidence in instruments can be developed only by skill in their use and frequent checks of their accuracy.

Pilots of single-place aircraft must be particularly careful in the use of flight plans, since there is no navigator available except the pilot himself. A pilot who claims that flying the airplane requires all his attention is in reality claiming that he is able to do only half his job. Accurate flight planning and accurate checks of position are necessary because instrument conditions may develop at any time, and unless the ground speed and definite course are known, the fuel consumption, gyro heading, and other important factors cannot be worked out without detailed computations requiring considerable time and attention.

YOU THINK YOU'RE THERE; BUT ARE YOU? UNLESS A PILOT KNOWS HE IS WHERE HE THINKS HE IS, HE IS IN DIFFICULTY

Many an experienced pilot can recall times when even in contact weather he became hopelessly lost or was forced down by lack of fuel because he did not follow elementary flight plan procedures. It can and does happen. When the ceiling and visibility is low, the situation becomes even more acute. To cite a typical example:

On a night flight, with the weather clear and unlimited, a pilot failed to check his position along a beacon-lighted airway. He had expected a tail wind but was actually not making good the speed he thought. To check his position he finally identified a beacon by its code flash and located it on his map. What he did not know was that while concentrating on his map he had permitted the plane to make a 180-degree turn, catching it just as it reached the reciprocal heading. Sure enough, there was the beacon passing below, flashing its code.

On the reciprocal course but reassured as to his "position," the pilot settled down to a contented hour of flying. His amazement and chagrin when he landed, for fuel, at his original point of departure, can be readily visualized.

THE MINIMUM SAFE ALTITUDE

A pilot should never take off without knowing the nature of the terrain and the elevation of obstructions along the route to be flown. The airways map must be closely examined and the highest points on the route prominently marked. From these notations a minimum safe altitude can be arrived at; the pilot should never fly lower than this minimum unless contact flight can be maintained with unlimited visibility.

In mountainous country, particularly in winter when the higher peaks are snow-covered, contact flight below the level of the highest terrain must be undertaken with caution. Snow-covered peaks frequently blend with the sky background or with the distant cloud bank; and if the visibility is poor, they may not be seen for what they are until too late.

On instrument flight, especially when a low approach on instruments must be made at a terminal, the correct ground elevation and the height of obstructions must be accurately known. The pilot should never assume that the terrain around an airport is level or be satisfied to know the elevation of an obstacle "within a few hundred feet." Even the western prairies have local hills that rise hundreds of feet, and the apparently level country side slopes upward toward the foothills of the mountain ranges.

Abrupt changes in elevation of the terrain have a definite influence on weather, particularly when the wind is blowing up the slope. A deck of stratus clouds over the lowlands will turn to dense fog over higher terrain. Many a pilot has been deceived by a "lowered ceiling" that was in reality up-sloping terrain.

From above an overcast, mountains or ridges below the clouds will frequently show as undulations in the top of the layer due to eddy currents above the crests of hills. This is, however, no accurate indication unless a steady wind is blowing at the lower level. If the wind is calm or light, the cloud decks will not show any variations even when mountain peaks rise to within a few hundred feet of the top of the cloud layer.

THE GROUND IS WHERE YOU HIT IT

As far as obstacles are concerned, it is never safe to make assumptions concerning your position unless you have a definite radio fix. The sort of trouble you can get into is illustrated by the following incident:

East bound on instrument in a snowstorm, a pilot was having trouble reading the radio range signals. While he was sure he was on course, he was not certain how far out he was from the range station. Since the country was mountainous, he held a safe altitude until he estimated his position to be a few miles west of his destination, an airport at elevation of 5,100 feet.

Following the on-course signal, the pilot slowly lost altitude, expecting to break out of the overcast at 6,000 feet. Below, the cloud became brighter. Since the altimeter indicated 6,300 feet, the pilot felt sure the base of the cloud was just below him. Almost simultaneously, however, he felt the wheels rolling over an uneven snow surface. The pilot did not throttle back his engines or level out from the climb which followed until he reached 10,000 feet.

When he let down the pilot was 25 miles short of his estimated position and just scraped the top of a mesa that rises abruptly above the surrounding terrain. The top of the mesa is covered with jagged rocks and cut by gullys, so the pilot is still wondering why the landing gear was undamaged.

NO GAS - NO GO

In planning a flight, the pilot must know the amount of fuel available and the hourly consumption at cruising speed. He should never assume that the fuel supply is sufficient for a flight simply because the tanks are full.

Military pilots are required to fly many different models of aircraft and often several variations of the same model. It is, therefore, not safe to depend upon memory, and the pilot should make a detailed check of fuel capacity and consumption before take-off. There is no sense in starting without enough fuel to get where you want to go.

When the weather is or may become adverse, the matter of fuel supply becomes doubly important. Time may be lost en route in avoiding bad weather. Additional time may be lost awaiting traffic clearance and making an instrument approach at the destination. The fuel consumption may increase when icing is encountered or carburetor heat applied. If the weather closes in at the destination and the fuel reserve is low, the pilot will have a limited choice of alternate landing fields. Many pilots have had only one choice, the field onto which their parachutes dropped them.

If fuel consumption is found, while en route, to exceed the estimate, immediate steps should be taken to conserve fuel, or the flight plan changed to a new destination well within the revised fuel range. Fuel may be conserved by reducing power, seeking a level where winds are more favorable, and with some engines, by reducing rpm. Do not rely to implicitly on an alternate airport where the weather may be questionable. The best alternate is plenty of fuel in the tanks.

The three factors so far discussed, course and distance, obstructions, and fuel range, are all non-weather factors. The next six all have to do with weather.

WEATHER AIDS TO AIR NAVIGATION

Weather stations are maintained at all major airports and air bases for the collection, analysis, and dissemination of weather information essential to flight operations. These stations are staffed by trained observers and forecasters who are available at all times to assist the pilot in his analysis of existing weather conditions and in his interpretation of forecasts.

If he is to make full use of the facilities provided by the weather service, a pilot must understand the material available, the way it is presented, and how to use the information to help solve his own flight problem. He must know how to use the weather station to best advantage.

SURFACE MAP FIRST

The most valuable source of information in the weather station is the weather map. You should study the weather map before you read the forecast or look over the later weather reports. The weather map presents a picture of the elements that will determine the weather. The air masses, fronts, and pressure systems shown on it will control the weather throughout the forecast period. Later weather reports will enable you to follow the movements of the weather systems, but you will find the local weather changes unexpected and difficult to explain unless you are first familiar with the over-all situation.

In examining the weather map, sketch in or mentally note the route to be flown. Then note the location of air masses, pressure systems, and fronts with respect to this route. Decide which elements will effect the flight, then exclude all others from consideration.

Next, compare the current weather map with previous charts. Note the direction of speed or motion of pressure systems and fronts. The forecaster will probably have computed these values in preparing his forecast. However, to fix the sequence firmly in mind it is well to make the comparison yourself.

Next, note the types of air mass prevailing over the route. Find out the stability of each and the type of modification which it will undergo during the period. Clouds, visibility, temperature, and dew point will usually give you clues, but the pseudo-adiabatic diagram will definitely tell you.

Study the type and movement of each front that lies across or near the airway. Estimate the movement of each. A front may slow up in one region but accelerate in another, and a front which originally crossed the airway at right angles may later parallel it.

When you have an idea of how the fronts, pressure systems, and air masses will move, inspect the map for indications of regions where fronts or cyclones are forming. Pressure troughs may be indistinct, and care must be used in studying the indications. When fronts have become stagnant or diffuse, always watch for indications of cyclone formation.

Valuable aids to the pilot's study of the weather are the Department of Commerce route and terminal forecasts transmitted every 6 hours over the C.A.A. teletype circuits. These forecast sequences present an evaluation of sky conditions, ceilings, and visibilities expected in the next few hours over the airways and at terminal airports.

NEXT, UPPER AIR CHARTS

With the type and movement of air masses, fronts, and pressure systems well in mind, inspect the upper air charts. These may be drawn separately or superimposed on the winds aloft charts. Be certain that the isobars are drawn at the same intervals as on the surface map, or note the difference.

In comparing the upper air pressure chart with the surface map, be sure to note the time of each. The upper air charts are drawn twice a day and may be 10 or 12 hours old. Note the relative position of pressure centers at each level. It is usual, rather than exceptional, for the pressure centers to be in different positions at different levels. This indicates that wind velocities and directions will change with altitude, and frequently the chart shows where there may be high-level weather activity connected with, but some distance away from, a surface center of activity. The position of pressure centers aloft frequently indicates how pressure centers at the surface may be expected to move. This feature is valuable in weather forecasting.

Upper air pressure maps are usually drawn for the 5-, 10-, and 20,000-foot level. When low clouds prevent the direct observation of winds aloft, these charts provide reliable information. The wind pattern can be visualized at a glance and remembered more accurately from the map than from winds aloft reports.

At upper levels, the wind will usually move nearly parallel to the isobars and the direction can, therefore, be seen immediately. The velocity can be accurately computed only by the use of the gradient wind scale or high-powered mathematics; however, if a few observations of velocity are available, the velocity at other points can be estimated with reasonable accuracy by comparison.

The winds aloft chart should next be examined and correlated with the surface chart and the upper air-pressure charts. Note particularly any marked changes in wind direction or velocity, expecially those not associated with fronts. From the winds aloft, you can find the position of fronts at the higher levels.

NOW, BRING IT UP TO DATE

The next step is to compare the hourly weather reports along the airway and recent pilot reports with the forecasts and the weather map. They should all agree. If they do not, go back over the analysis and try to find out how they can be made to agree. Reexamination will usually clarify the matter.

DO YOUR OWN THINKING

Such an analysis can be made without help from a forecaster. If a forecaster is available, the pilot will have had much of the work done for him but he should nevertheless make a weather analysis for himself. A pilot is negligent in the performance of his duties if he accepts an analysis or forecast with which he does not agree, or which he does not completely understand.

The objective of the detailed review of charts and other weather information is to give the pilot a complete picture of the weather conditions and developments that will effect flight along his route. Once in the air, he cannot consult the forecaster or the maps to seek explanations for unexpected changes. He must then rely on his weather knowledge and experience and on the information he obtained before leaving the ground.

Most forecasters use pseudo-adiabatic diagrams of upper air observations in making an analysis. A pilot should be thoroughly familiar with this diagram so that he may estimate accurately the height of the freezing and ice crystal levels, cloud levels, and regions of turbulence in case a forecaster is not available.

His weather analysis completed, the pilot will now be ready to continue the preparation of his flight plan.

WHERE ARE THOSE WEATHER HAZARDS?

From his analysis of the various charts and reports, the pilot now knows the horizontal extent of weather conditions along his route and the types of weather that will be associated with the various fronts and air masses. The vertical extent of weather conditions must be estimated by indirect analysis or by careful study of recent pilot reports.

The advice of an experienced forecaster should be sought in estimating the vertical extent of weather and the structure of storms and clouds. The forecaster has the benefit of local experience, contact with other pilots, and a thorough weather training. The pilot should utilize his services to the fullest extent and never be satisfied with anything less than a complete, detailed report.

Also, a forecaster is likely to be more painstaking and his forecast more accurate if he knows that the pilot using his forecast is really interested in "knowing what the score is" and will use the forecast intelligently.

In estimating the horizontal and vertical extent of weather conditions the following points are important:

1. The height of the freezing level and its variations.

2. The type and intensity of icing.

3. The regions of turbulence.

4. The base and top of cloud layers and whether overcast, broken or scattered (all of these factors can be estimated with accuracy by consulting the pseudo-adiabatic diagrams for the stations along or near this route.)

5. Location and movement of local showers, squalls, and thunderstorms.

6. Ceiling and visibility along the route, at the destination, and at alternate airports.

7. Other possible hazards, such as heavy precipitation, etc.

When these conditions have been checked, several altitudes at which flight may be conducted ought to appear. The selection of flight path will then be determined by winds, the consideration of contact or instrument flight rules, and, on short flights, the duration of the flight.

GOING WITH THE WIND

Wind velocity and direction can be obtained either from winds aloft reports, upper air-pressure maps, or forecasts from the surface maps. These are to be preferred in the order named. No pilot should ever depart without at least a forecast of winds aloft. Neither should he use winds aloft observations without consideration of forecasted changes.

In evaluating winds aloft reports, the pilot should realize that a horizontal wind is the exception. Air has vertical as well as horizontal movement. On short flights this may not be important, but on longer flights it may materially affect fuel consumption.

Never let a strong tail wind influence your choice of altitude if it will lead you into unfavorable weather. Direct observations of winds aloft can be made only below the clouds, and frequently the reports will not represent correctly the winds in the storm area.

Another frequent source of error lies in the disturbance of a wind stream by draft and turbulence. During the afternoon or at other times when cumulus clouds indicate the pressure of strong vertical currents, winds aloft reports may be misleading. Flight below the cloud bases will encounter turbulence which may slow it down. Flight between cumulus clouds will be made through sinking air, and a slight climb must be maintained, diminishing the air speed; time will also be lost avoiding the clouds. These adverse effects may nullify the advantages of a tail wind at these levels.

In selecting the most advantageous wind it is necessary to consider both the winds aloft and the weather conditions. Freedom from turbulence and icing will often help more than a tail wind to expedite the flight.

TIME AND A HALF

When this stage in planning the flight has been reached, possible changes in wind and weather during the flight will have been considered. However, a pilot should not be satisfied with a forecast covering only the estimated duration of his flight. In every case, forecasts should be for a period at least one-half again as long as the actual flying time. If the take-off is delayed or a landing en route becomes necessary, the flight plan can then be adjusted within the forecast period.

HIS FAVORITE ALTITUDE

The flight plan finally selected depends not only on wind and weather but also on terrain. Some pilots develop a habit of automatically choosing a favorite altitude without regard to other factors. This practice may be satisfactory for the pilot who always flies the same route and can wait for the kind of weather he likes. Over unfamiliar terrain or when flight must be made regardless of weather, the selection of the altitude demands consideration of every factor. Pilots must not permit habit to govern their choice of altitude.

The hazard of this practice is well illustrated by an incident that occurred recently along the west coast.

In preparing for a flight from San Francisco to Seattle an Army pilot filed a flight plan, carefully computed his estimated time over check points and his destination, but requested an altitude of 5,000 feet. Airways Traffic Control approved the flight plan but suggested a high altitude. Willingly, the pilot changed it to 7,000 feet. Again ATC questioned the selection. The pilot, perplexed, asked for a recommended altitude. The ATC operator advised that if he desired to avoid all obstacles by a safe margin the minimum altitude would be 11,000 feet! Be sure your favorite altitude, if you make the mistake of having one, doesn't involve flying part of the way underground.

DO YOUR SECOND GUESSING FIRST

Weather forecasting is not an exact science, nor can the pilot depend upon faultless operation of aids to instrument flight. A ceiling may lower to zero, contrary to the forecast; light snow may become heavy snow at a terminal just prior to landing. The radio in the plane or the facilities on the ground may fail. The pilot will then have to find an airport where weather permits an approach by contact flight rules.

An alternate airport should be a part of every flight plan. Its selection and the making of a flight plan from the intended destination to the alternate must not be left until an emergency threatens. When an alternate flight plan has been properly prepared, and necessity for its use arises, the flight can proceed methodically and an emergency is, thereby, avoided.

The principles that guide the pilot in making his basic flight plan apply equally well to the alternate flight plan. However, even greater accuracy is desirable since the plan will not ordinarily be used until the later part of the flight. The forecast must be reliable and a leeway must be allowed for error.

Do not place too great dependence on an alternat flight plan if weather conditions are critical. It is bet ter to land at an intermediate point where weather in formation and fuel are available.

MERCURY MEANS WHAT IT SAYS

Whenever an instrument flight is planned or an instrument approach at destination may be required, it is essential that the latest altimeter setting be known in event of radio failure or silence. On short flights over level ground the altimeter settings are not so important, since pressure differences encountered will be small. However, when the wind is strong, the range of ground elevation great, or the flight long, the change in altimeter setting will be frequently sufficient to make an instrument approach highly dangerous.

Before taking off, you should note the altimeter setting at selected points along the route together with the pressure changes at each point for the last 3 hours. These data are included in the station weather reports.

If the altimeter setting at the point of departure is 30.10 inches and at the destination is 29.62 inches, rising 0.09 inch in the last 3 hours, it may be estimated that after a 4-hour flight the pressure will have risen 0.12 inch and that the altimeter setting will be 29.74 inches.

On long flights, particularly when entering a low-pressure area or a colder air mass, the pilot should always compute the altimeter error on the basis of the free air temperature unless he is assured of clearing obstacles by a margin of more than 2,000 feet. Remember the following rules:

WHEN AIR TEMPERATURE AT FLIGHT ALTITUDE IS BELOW STANDARD, THE TRUE ALTITUDE IS LESS THAN INDICATED: WHEN THE AIR TEMPERATURE IS ABOVE STANDARD, THE TRUE ALTITUDE IS MORE THAN INDICATED. WHEN FLYING TOWARD LOWER PRESSURE, THE TRUE ALTITUDE BECOMES LESS THAN INDICATED. WHEN FLYING TOWARD HIGHER PRESSURE, THE TRUE ALTITUDE IS MORE THAN INDICATED.

USE OF THE COCKPIT CHECK LIST

The modern airplane is undoubtedly the most complicated mechanical unit ever operated by a single individual. Multiengine airplanes, because of their intricacy of design, frequently require the service of a second pilot and engineer, particularly during take-off and landing. The numerous controls and adjustments will demand the undivided attention of the crew.

The elements that must be checked, the controls that must be adjusted, and the duties that must be performed by the crew during the preparation and take-off of a flight are so numerous that they cannot be safely committed to memory.

To insure that all items will be taken care of, each airplane is now equipped with a check list for the pilot to follow before take-off, during flight, and in preparing to land. The use of this list will help prevent costly errors, or disaster from failure to make

minor but important adjustments of controls. It is of particular value to pilots who must fly several different types of aircraft and may forget certain procedures which apply to a particular type.

A pilot should never be so cocksure of himself that he neglects to use the check list. All of the check list for a four-engined bomber can't be carried in your head. The pilot should take nothing for granted. He should leave nothing to chance. In warfare you are going to need all your supply of luck. Don't waste any of it by guessing at what you should know for sure.

Supplement

ANALYSIS OF PSEUDO-ADIABATIC DIAGRAMS

STABILITY

The importance of determining the stability of various layers in the atmosphere has been demonstrated throughout the foregoing discussions of weather phenomena. It has been shown that the degree of stability or instability of the air in the warm air mass is the determining factor for the type and intensity of the weather produced by both warm and cold fronts. It is self-evident that the type and degree of stability will determine the weather within the boundaries of any given air mass. Pilots have learned from experience that stable layers of air tend to have stratus type clouds rather than cumuliform, rime icing in clouds rather than glaze, smooth flying rather than rough, and poor visibilities due to fog or smoke in layers rather than the clear air typical of turbulent unstable air.

In most cases all the pilot need do is ask the forecaster the location and vertical extent of layers with differing stability. Any experienced forecaster can immediately answer these questions and will volunteer further, more practical, and detailed information. But, it would be unsafe to assume that all forecasters are experienced or even that there will always be a forecaster available to question.

The answers to these questions, in fact, the complete picture of the vertical structure of the atmosphere in terms of temperature, pressure, and humidity is incorporated in the pseudo-adiabatic diagram plotted by all weather stations for a selected group of strategically located radiosonde units. "Raob," or radiosonde observations, are made twice daily, at noon and midnight, by upwards of 50 Army, Navy, and Weather Bureau stations comprising the basic "raob" teletype network. The data from each station's sounding is representative of the air mass overlying the surrounding area. The interpretation of these "raob" soundings in order to answer the pilots' questions is not so difficult as popularly supposed.

Fundamentally the pseudo-adiabatic diagram is nothing more or less than a graph on which is plotted temperature against pressure or altitude. When the "raob" sounding is plotted and the curve of the change of temperature with increasing altitude is completed, this line becomes known as the "lapse rate" or "free air temperature curve." The observer, in plotting the curve, places the relative humidity of the air which prevails at that level to the right of the point in percentage figures. (See figure 1.)

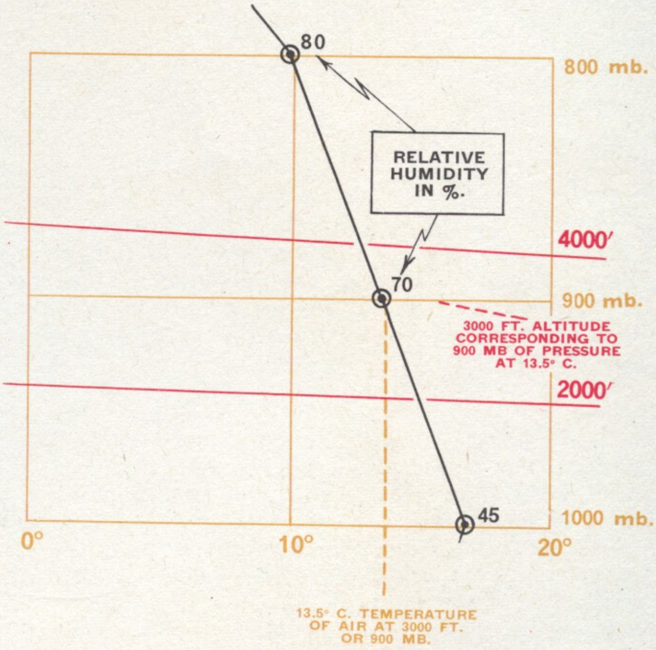


Figure 1

The diagram in practice has three sets of reference lines printed over the basic graph. For the thermodynamics involved in arriving at these lines, the pilot is referred to any text on meteorology. These lines are used for reference only, to aid ready comparison of the data as it exists (the free air temperature curve) with the theoretical possibilities.

The first of these lines, the so-called dry adiabat (the sloping brown line, figure 2), is based upon the fact that the air temperature of a sample of air decreases as the pressure is decreased - the energy content of the sample remaining constant. Everyone is familiar with the fact that a bicycle pump heats as it is used. This heating is due to compression of the air - an increase of temperature with increased pressure. The rate of cooling (decrease of temperature) for a parcel of dry air upon being lifted through decreasing pressures is approximately 8^{o} C/100 mb,

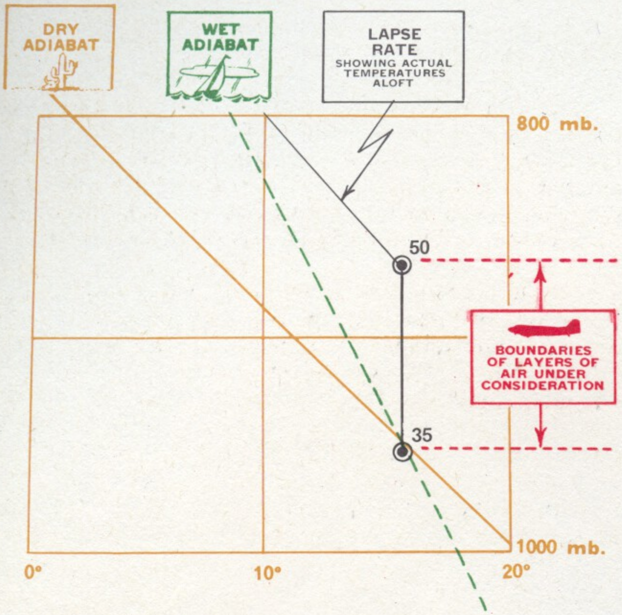


Figure 2

or 3° C/1000 feet in the lower levels of the atmosphere. These dry adiabats are spaced on the diagram for each two degrees of temperature, and in using them for reference the forecaster merely interpolates between lines.

The second of these lines, the moist or pseudo-adiabat (the curved, dashed green line, figure 2), is used when theoretically lifting a parcel of "wet" air. (In theory, air is wet when the relative humidity is 100 percent and dry when humidity is less than 100 percent.) It is easily seen that when this wet air cools upon being lifted or expanded, it must give up some water vapor since humidities in excess of 100 percent are impossible outside the laboratory. Hence condensation will take place and at the same time heat will be released to the parcel of air as a consequence of the change of phase. All this means simply that "wet" air will cool at a lesser rate upon being lifted through decreasing pressures than dry air. This rate, however, is not nearly as constant as that for the dry adiabat because of the added complication of moisture. It averages 4° C/100 mb, or 1.5° C/1000 feet in the lower levels, but the rate is less than that for very warm wet air and approaches the dry adiabat rate at the cold end of the temperature scale.

The third set of lines are lines of constant mixing ratio or specific humidity (the straight solid green lines, figure 7). Each shows how much water vapor the air can hold at any given temperature and pressure. By multiplying the figure by the relative humidity, the forecaster can find out how much water vapor the air actually does hold at any certain level.

STABILITY AND INSTABILITY

The stability of any layer of the atmosphere is very easy to determine simply by a comparison of the slope of the free air temperature curve with the slope of either of the two adiabats. The first step is to determine whether the air within the layer under consideration is wet or dry. Is the average of the figures for relative humidity 100 percent or less? (In actual practice a humidity of 85 percent or over in the higher levels of the atmosphere indicates the presence of a cloud and "wet" air.) If the air is "dry" compare the slope of the temperature curve with the nearest dry adiabat. The closer the slopes agree, the less stable the air in the layer under consideration will become. A situation in which the lapse rate exceeds that of the dry adiabat - a decrease of more than 3° C/1000 feet - would be termed "absolute instability." But, such a situation occurs so rarely in the atmosphere, that for all practical purposes it can be considered impossible on a diagram except in the lowest layer. (See figure 3.)

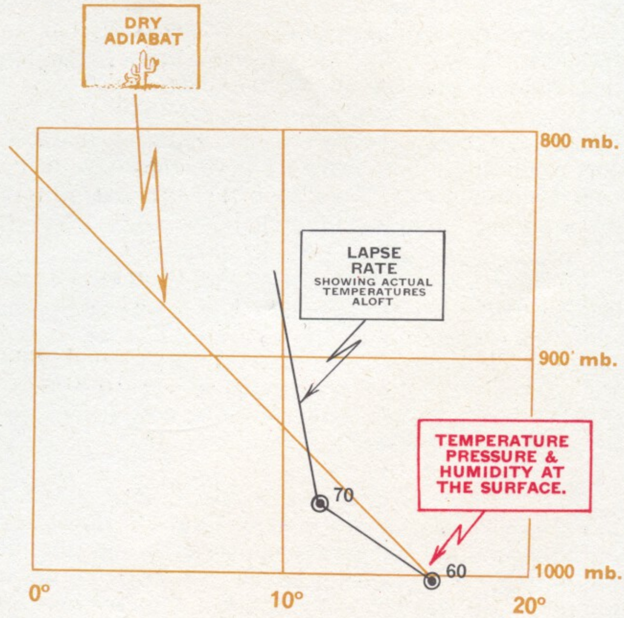


Figure 3

The opposite situation - "absolute stability" - is very common, however, and is termed an "inversion." Here the free air temperature decreases only slightly or may increase aloft, less than the rate for either the dry or wet adiabat. In terms of slopes - the slope of the free air temperature curve will be more nearly vertical or exceed the vertical to the right in comparison with either adiabat. (See figure 2.)

DETERMINATION OF STABILITY

Step 1. Choose a layer of air which includes the proposed flight level. Think of a layer as the straight

Supplement

ANALYSIS OF PSEUDO-ADIABATIC DIAGRAMS

STABILITY

The importance of determining the stability of various layers in the atmosphere has been demonstrated throughout the foregoing discussions of weather phenomena. It has been shown that the degree of stability or instability of the air in the warm air mass is the determining factor for the type and intensity of the weather produced by both warm and cold fronts. It is self-evident that the type and degree of stability will determine the weather within the boundaries of any given air mass. Pilots have learned from experience that stable layers of air tend to have stratus type clouds rather than cumuliform, rime icing in clouds rather than glaze, smooth flying rather than rough, and poor visibilities due to fog or smoke in layers rather than the clear air typical of turbulent unstable air.

In most cases all the pilot need do is ask the forecaster the location and vertical extent of layers with differing stability. Any experienced forecaster can immediately answer these questions and will volunteer further, more practical, and detailed information. But, it would be unsafe to assume that all forecasters are experienced or even that there will always be a forecaster available to question.

The answers to these questions, in fact, the complete picture of the vertical structure of the atmosphere in terms of temperature, pressure, and humidity is incorporated in the pseudo-adiabatic diagram plotted by all weather stations for a selected group of strategically located radiosonde units. "Raob," or radiosonde observations, are made twice daily, at noon and midnight, by upwards of 50 Army, Navy, and Weather Bureau stations comprising the basic "raob" teletype network. The data from each station's sounding is representative of the air mass overlying the surrounding area. The interpretation of these "raob" soundings in order to answer the pilots' questions is not so difficult as popularly supposed.

Fundamentally the pseudo-adiabatic diagram is nothing more or less than a graph on which is plotted temperature against pressure or altitude. When the "raob" sounding is plotted and the curve of the change of temperature with increasing altitude is completed, this line becomes known as the "lapse rate" or "free air temperature curve." The observer, in plotting the curve, places the relative humidity of the air which prevails at that level to the right of the point in percentage figures. (See figure 1.)

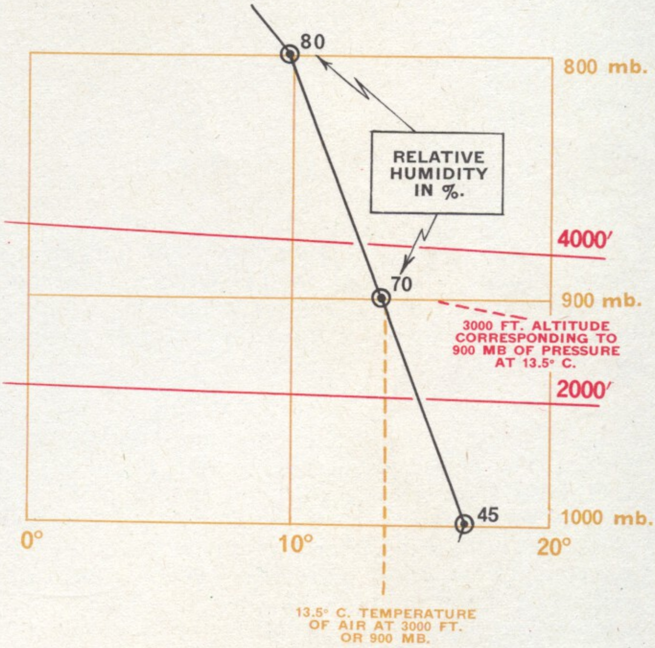


Figure 1

The diagram in practice has three sets of reference lines printed over the basic graph. For the thermodynamics involved in arriving at these lines, the pilot is referred to any text on meteorology. These lines are used for reference only, to aid ready comparison of the data as it exists (the free air temperature curve) with the theoretical possibilities.

The first of these lines, the so-called dry adiabat (the sloping brown line, figure 2), is based upon the fact that the air temperature of a sample of air decreases as the pressure is decreased - the energy content of the sample remaining constant. Everyone is familiar with the fact that a bicycle pump heats as it is used. This heating is due to compression of the air - an increase of temperature with increased pressure. The rate of cooling (decrease of temperature) for a parcel of dry air upon being lifted through decreasing pressures is approximately 8^{0} C/100 mb,

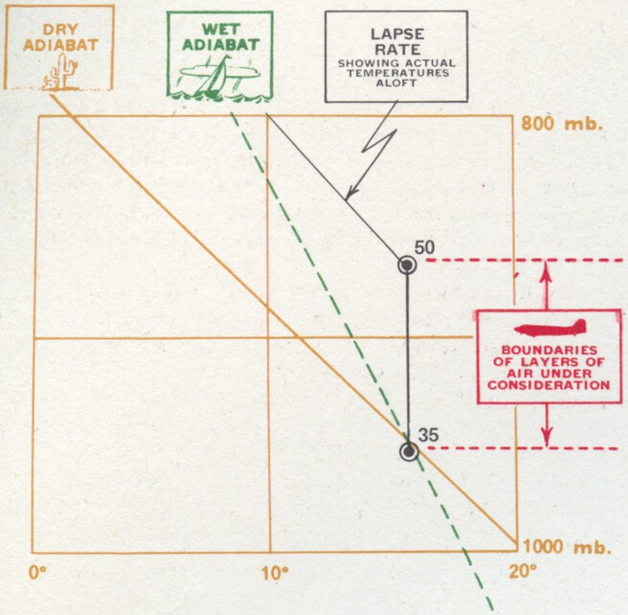


Figure 2

or 3° C/1000 feet in the lower levels of the atmosphere. These dry adiabats are spaced on the diagram for each two degrees of temperature, and in using them for reference the forecaster merely interpolates between lines.

The second of these lines, the moist or pseudo-adiabat (the curved, dashed green line, figure 2), is used when theoretically lifting a parcel of "wet" air. (In theory, air is wet when the relative humidity is 100 percent and dry when humidity is less than 100 percent.) It is easily seen that when this wet air cools upon being lifted or expanded, it must give up some water vapor since humidities in excess of 100 percent are impossible outside the laboratory. Hence condensation will take place and at the same time heat will be released to the parcel of air as a consequence of the change of phase. All this means simply that "wet" air will cool at a lesser rate upon being lifted through decreasing pressures than dry air. This rate, however, is not nearly as constant as that for the dry adiabat because of the added complication of moisture. It averages 4° C/100 mb, or 1.5° C/1000 feet in the lower levels, but the rate is less than that for very warm wet air and approaches the dry adiabat rate at the cold end of the temperature scale.

The third set of lines are lines of constant mixing ratio or specific humidity (the straight solid green lines, figure 7). Each shows how much water vapor the air can hold at any given temperature and pressure. By multiplying the figure by the relative humidity, the forecaster can find out how much water vapor the air actually does hold at any certain level.

STABILITY AND INSTABILITY

The stability of any layer of the atmosphere is very easy to determine simply by a comparison of the slope of the free air temperature curve with the slope of either of the two adiabats. The first step is to determine whether the air within the layer under consideration is wet or dry. Is the average of the figures for relative humidity 100 percent or less? (In actual practice a humidity of 85 percent or over in the higher levels of the atmosphere indicates the presence of a cloud and "wet" air.) If the air is "dry" compare the slope of the temperature curve with the nearest dry adiabat. The closer the slopes agree, the less stable the air in the layer under consideration will become. A situation in which the lapse rate exceeds that of the dry adiabat - a decrease of more than 3° C/1000 feet - would be termed "absolute instability." But, such a situation occurs so rarely in the atmosphere, that for all practical purposes it can be considered impossible on a diagram except in the lowest layer. (See figure 3.)

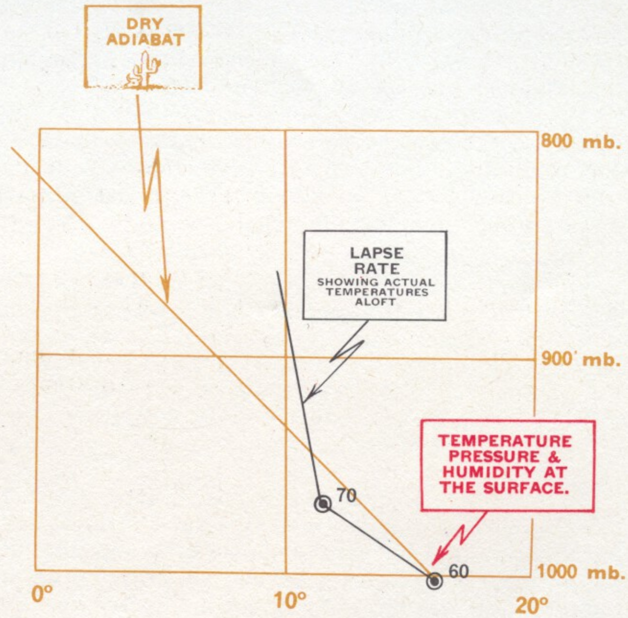


Figure 3

The opposite situation - "absolute stability" - is very common, however, and is termed an "inversion." Here the free air temperature decreases only slightly or may increase aloft, less than the rate for either the dry or wet adiabat. In terms of slopes - the slope of the free air temperature curve will be more nearly vertical or exceed the vertical to the right in comparison with either adiabat. (See figure 2.)

DETERMINATION OF STABILITY

Step 1. Choose a layer of air which includes the proposed flight level. Think of a layer as the straight

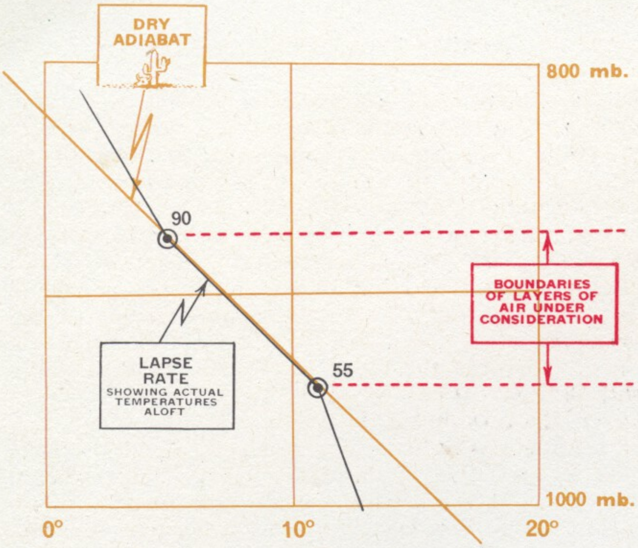


Figure 4

line between two points on the lapse rate curve.

Step 2. Determine whether the air in the layer is "wet" or "dry." Is the average relative humidity more or less than 85 percent?

Step 3. Choose an adiabat intersecting the lower part of the layer being analyzed for stability. It may be necessary to interpolate another adiabat between those already printed on the chart.

Step 4. General rules for the determination of stability from the diagram may now be set down:

a. Stable lapse rates (free air temperature curves) slope to the right of the adiabat concerned. (See figures 2 and 5.)

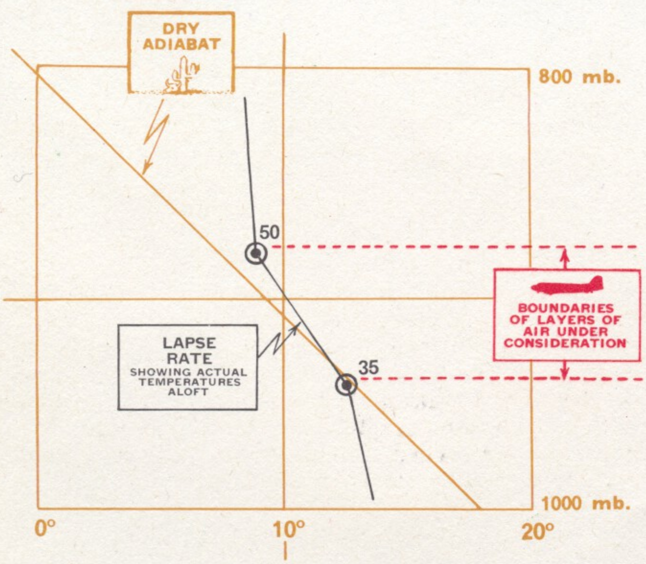


Figure 5

b. Unstable lapse rates slope to the left of the adiabat concerned. (See figure 6.)

c. The more nearly parallel the lapse rate is to the dry adiabat the more unstable the air in that layer becomes. A lapse rate exactly parallel to the dry adiabat is the most unstable situation represented in the upper levels of the atmosphere and turbulence may here reach its greatest intensity. (See figure 4.)

d. A condition in which the slope of the free air temperature curve lies anywhere between that of the dry and wet adiabat is termed "conditional instability." The air in such a layer will be stable if "dry" and unstable if "wet." (See figures 5 and 6.)

DETERMINATION OF ICING LEVEL

To find the freezing level, simply note the pressure at which the lapse rate crosses the 0° C temperature

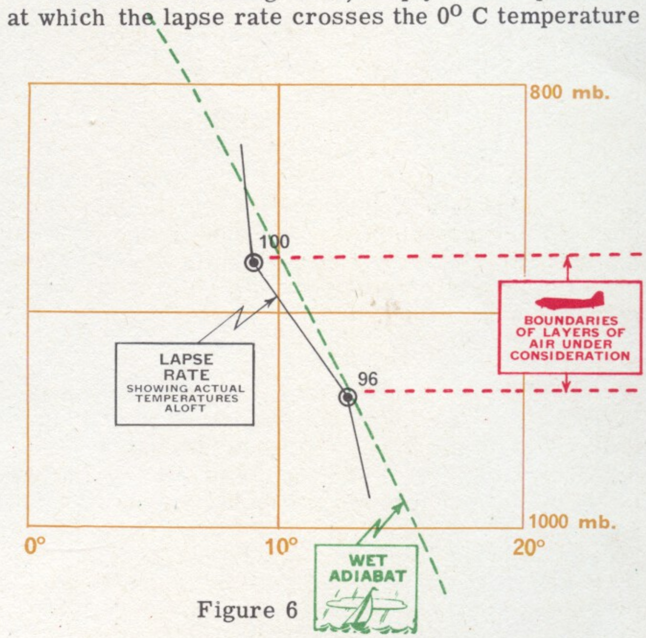


Figure 6

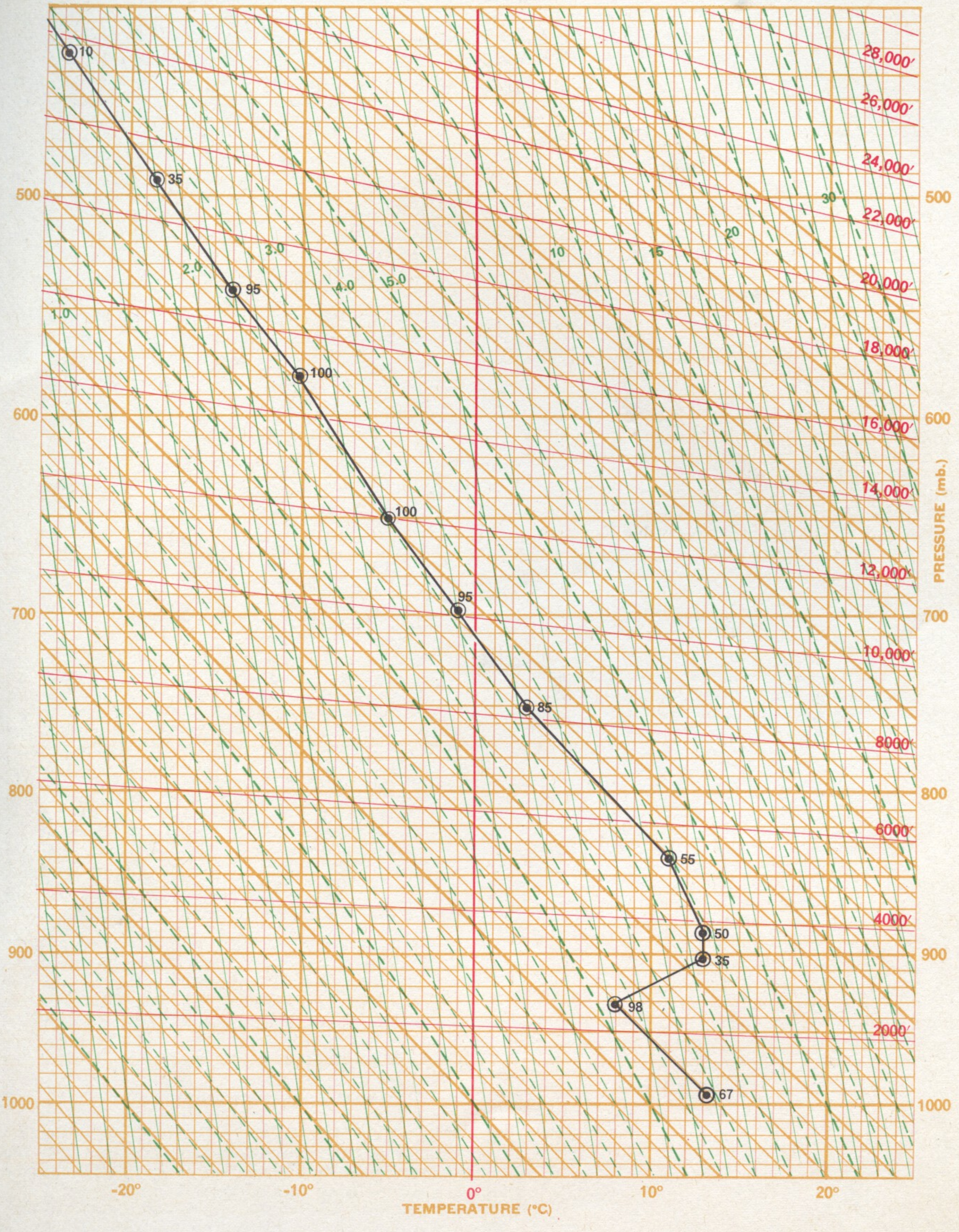
line. Some diagrams have an additional reference line for altitude, even thousand foot levels being represented. If such a chart is not being used, however, conversion tables changing pressure in millibars to altitude in feet will be available.

Icing is possible anywhere above this level if water in the liquid state is present. Liquid moisture will be indicated by relative humidities approaching 100 percent. With suitable humidity, lapse rates unstable for "wet" air will indicate glaze icing above the 0° isotherm; lapse rates stable for "wet" air will indicate the probability of only rime.

DETERMINATION OF CLOUDS

Cloud levels - thickness of cloud and top of the overcast may be estimated with accuracy from the relative humidity figures and sharp changes in the slope of the lapse rate curve.

PSEUDO-ADIABATIC DIAGRAM



The pilot now has all the information necessary for a practical analysis of any but the most complex lapse rates. Reproduced on the page facing is the RAOB sounding for St. Louis at noon on a day during the fall of the year.

First, look at the general shape of the curve; the most prominent feature is the inversion, showing that a very stable layer of air exists between 2500 and 3500 feet. Note that the relative humidity is 98% at the base of the inversion. Moisture will exist in visible form at this humidity, so expect a layer of broken or overcast clouds whose base will be about 2000 feet and will be topped by the base of the inversion—2500 feet. A glance at the hourly sequence report for LS will confirm or deny the assumption. Because the lapse rate below the inversion is *unstable* for *wet* air, except light turbulence within and below these clouds, the presence of the inversion will damp out the acceleration of the vertical currents and prevent the development of moderate or severe turbulence.

The next most prominent feature is the high humidity of the air above 8000 feet. Since a humidity of 85% denotes the probability of clouds, it may certainly be assumed that the clouds exist at humidities of 100%. The slope of the lapse rate from 8000 to 12,000 feet is shown to be unstable by comparison to the nearest wet adiabat. The cloud will then display the unstable characteristics of the cumuliform clouds—at this elevation either stratocumulus or altocumulus. Above 12,000 feet the lapse rate is shown in the same manner to be stable and the cloud exhibits the more stable characteristics of stratiform clouds.

The next step is the determination of the freezing level. It will be noted that the lapse rate crosses the 0° C temperature line at 710 milibars or approximately 9500 feet. This, then, is the freezing level. Since clouds exist above this level, icing may be found from 9500 feet upward. Expect clear ice or glaze in the unstable cloud up to 12,000 feet. Above 12,000 feet, rime should be expected in the stable clouds.

CHOOSING THE BEST FLIGHT LEVEL

The best flight level will avoid not only turbulence and icing hazards, but will avoid the nervous strain of prolonged, close attention to the flight instruments. The best flight path, then, is between cloud layers with a good horizontal visibility. The sounding for St. Louis shows the absence of clouds and turbulence with air temperatures above freezing between 2500 feet and 8000 feet. Visibility will be restricted only by a light to moderate rain falling from the thick cloud layer above. The actual altitude chosen will depend upon the winds aloft forecast.

Tactical aircraft with adequate deicing equipment might ascend through the icing zones to the clear air indicated above 17,000 feet. This ascent would be extremely risky and obviously unnecessary with good flight altitudes available below the freezing zone.