CIVIL AIR PATROL
AUXILIARY UNITED STATES AIR FORCE

DESIGNED AND LITHOGRAPHED by HENNAGE • WASH., D. C.

NAVIGATION AND THE WEATHER

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NAVIGATION
AND THE
WEATHER

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Foreword

The history of mankind is essentially a record of the conquests he has made over his environment. Foremost among such achievements has been his victories over the obstacles he has met when traveling or conveying his possessions from one place to another. He devised the boat with which he crossed the streams that lay in his path; he developed the wheel which made easier the transportation of his goods over land surfaces; finally, he invented the airplane which enabled travel through the skies.

Early man found his way from one place to another by means of prominent landmarks. When boats became ships that sailed the seas and travel distances began to increase, methods of navigation grew in complexity. Today, navigators employ the devices of radio and electronics.

Yet, wherever man travelled, in whatever period of time, he was concerned not only with finding his way but also with the weather. He found that the circumstances of the weather could prove a hindrance or a help.

As one travels the pathway of life, like the navigator he must chart a course, and like the navigator he must be alert to the circumstances which will affect the course he charts. The complexities of modern life requires that American youth be prepared to chart his life's course wisely.

The Civil Air Patrol is dedicated to the service of youth in the age of aviation. Aware of youth needs, it has prepared an aviation education series. It is our hope and expectation that the information this series contains will help young people plan and act so that they avoid some of the hazards the future may hold.

WALTER R. AGEE
Major General, USAF
National Commander
Civil Air Patrol

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Preface

Navigation and the Weather is one of a series of six pocket-sized books prepared for use in the aviation education program of the Civil Air Patrol. It is to be used with an instructional 35 mm. color, sound filmstrip illustrating the concepts it introduces.

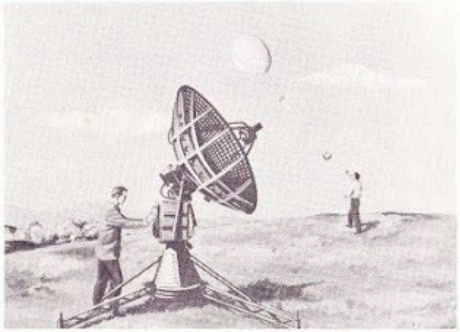
The purpose of the book is to describe in terms of secondary-school student understandings the types of navigation, the principles and practices of each, and the weather as a factor in navigation. The intent of the book is not to present an exhaustive study of these areas. Rather it is to help the student lay a foundation for further study in the fields of navigation and the weather should his interests dictate such study. However, its content is sufficiently detailed to challenge the general interest of students and air-minded adults.

Although the first use of the book will be with Civil Air Patrol cadets, it will be found to have other uses. This book and the others of this series will be found of value to students, teachers, and adult groups engaged in any aviation-study program. This series is rich in information which provides both content for the secondary school course in general aviation and materials for enriching the content of science and social studies classes.

The advice on technical matters received from the Civil Air Patrol Headquarters, Office of Operations and Training, and the advice on educational matters provided by the Aviation Education Personnel helped materially in the preparation of this book. Special acknowledgement is also due to Mr. Irving Ripps of the Civil Air Patrol, Office of Information Services, and to contributing members of the Civil Air Patrol National Commander's Aviation Education Committee for suggestions and advice offered. The names of the members of the three groups mentioned above appear elsewhere in this booklet.

MERVIN K. STRICKLER, JR.
Director of Aviation Education

Weather charts and maps were made available through courtesy of the Weather Bureau and the Civil Aeronautics Administration.



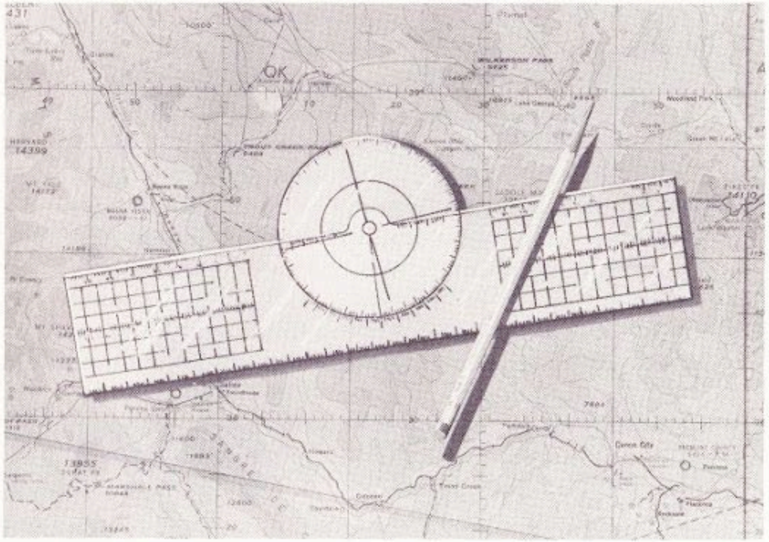
CHAPTER ONE

I. INTRODUCTION

There are several tasks that every pilot performs before "take-off." Among these are to (1) obtain proper charts, (2) check the weather, (3) compute the range of his plane and select refueling points, (4) lay out his course, (5) study the chart for landmarks and (6) file a flight plan. Two of these tasks which require first attention are (1) to chart his course and (2) to learn the kind of weather he will likely encounter along his route.

The importance of the aeronautical chart.

In order to chart his course properly, the pilot needs to have the right kind of instruments, an understanding of the proper procedures, and the proper sectional or world aeronautical charts. A pilot so equipped uses pencil, scale, and protractor or plotter (1) to draw a true course line or lines from his point of departure to his destination,



Plotting the Course

(2) to mark check points along this line, (3) to measure the distance from his point of departure to each, and (4) to find the direction of each course line drawn. He must also learn from the chart (1) the location of danger areas and restricted areas (such as Air Defense Identification Zone (ADIZ) areas), (2) land marks, (3) the nature of the terrain (the earth's surface) over which his flight will take place and, (4) "man-made" obstacles to safe flight.

Aeronautical charts are published by the United States Coast and Geodetic Survey. Three types of aeronautical charts are most useful in air navigation: the Sectional Charts (scale, 8 statute* miles to an inch), the World Air Charts (scale, 16 statute miles to an inch), and the Aeronautical Planning Charts (scale, 80 miles to an inch).

The importance of weather information.

A pilot cannot chart a proper course unless he knows something of the prevailing weather conditions or those likely to occur along the path of his flight.

He may under certain conditions (for example, Visual Flight Rules) plan his course so that his flight avoids clouds, fog, or blowing dust which would obscure the surface over which he flies. He must always take into account the effect of the wind upon his flight and take advantage of favorable winds. In fact (as you will soon discover) the speed and direction of the wind are very important factors in navigation. Unless a pilot knows the wind conditions affecting his flight, he cannot solve navigation problems involving (1) compass headings, (2) wind drift, (3) ground speed, (4) climb and descent time, and (5) fuel consumption in relation to distance flown.

As a matter of fact, information about the weather is so important to safe flight that radio-range signals are interrupted periodically so that weather information can be broadcast to pilots in flight. Moreover, a pilot in flight may obtain weather information from any radio communication station.

Before beginning a flight operation, pilots may obtain information from the Weather Bureau, from Flight Information Service, or, in the case of airline pilots, from the airlines' meteorological service. Such information is communicated not only directly and by means of radio, but also by means of maps and reports.

* A statute mile is 5,280 feet. A nautical mile is 6,080 feet, or 1/60 of a degree of the earth's equator.

The role of the pilot in weather forecasting.

The fact that weather information is so readily available to the pilot does not mean that his only responsibility in terms of weather is to check with weather information services. He must also know how to interpret the weather information he receives. Before he can do this he must understand the map and report symbols used by meteorologists. Again, the weather factors used by meteorologists when they make weather forecasts are so complex that forecasts are subject to continuing amendment. By reason of this same complexity of weather factors, unexpected weather changes are always a possibility. Consequently, pilots must know, and all of us should know, the signposts of the weather such as different cloud types. Pilots also should be able, on the basis of current weather data, to foresee weather conditions—such as fogs, thunderstorms, and icing conditions—which might prove hazardous to safe flight.

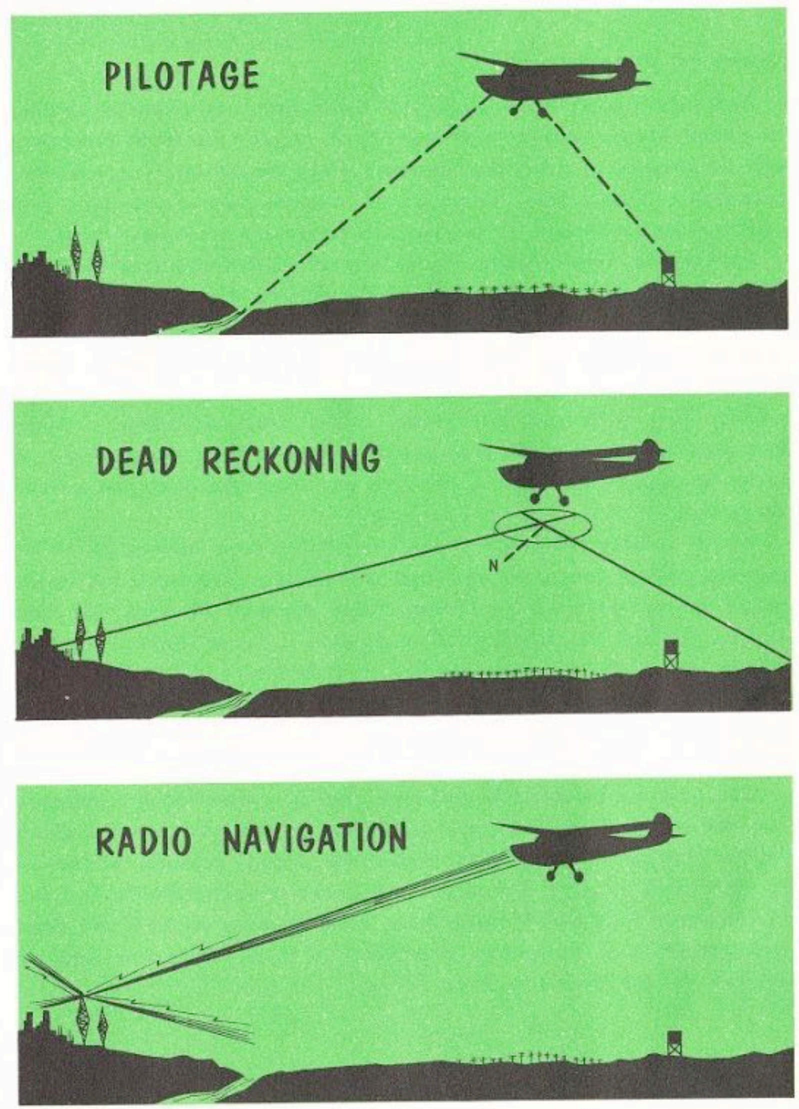
The importance of weather charts.

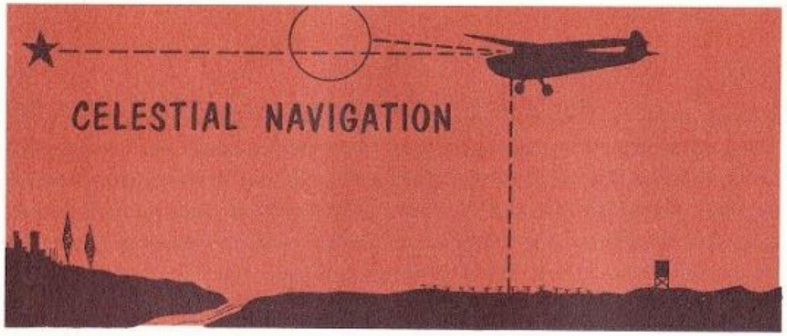
Weather charts are published by the United States Weather Bureau. Among the most important of these are Surface Weather Maps, Winds Aloft Charts, Constant Pressure Charts, and Prognostic Charts. Surface Weather Maps are prepared from weather observations taken simultaneously at 0130, 0730, 1330, and 1930, Eastern Standard Time by the several hundred U. S. Weather Observation Stations; Winds Aloft Charts are prepared four times each day from information supplied by approximately 125 stations spaced throughout the United States; Constant Pressure Charts and the Prognostic Charts help discover changes in the weather pattern that will be important to flight operations.

Although weather charts are of importance to pilots, they are of greater importance as the tools which enable meteorologists to make their forecasts. Moreover, important as weather charts are to pilots, of greater importance are the *weather sequence reports** from stations along the flight path and the *weather forecasts* covering the route to be flown and the airports at which landings are intended. It is interesting and significant that in addition to reports from weather stations, reports of weather encountered by pilots in flight (PIREPS) are used by weather forecasters. As a matter of fact, pilots must be always aware of the current state of the weather. All flight planning and all navigation types must take wind and weather factors into consideration. Unless this is done, a proper VFR (Visual Flight Rules) course cannot be charted; a proper compass heading cannot be determined; the ground speed and time of arrival at a proposed airport cannot be calculated.

* Weather reports which are prepared in a continuing series.

Types of Navigation





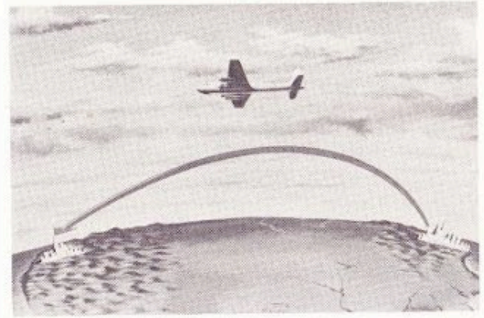
Types of navigation.

Aerial navigation is the science of flying from one place to another as directly as circumstances will allow. A part of the flight procedure can be planned in advance. However, since all the circumstances surrounding a flight cannot be predicted, another part of the flight procedure must be decided as unexpected conditions are encountered.

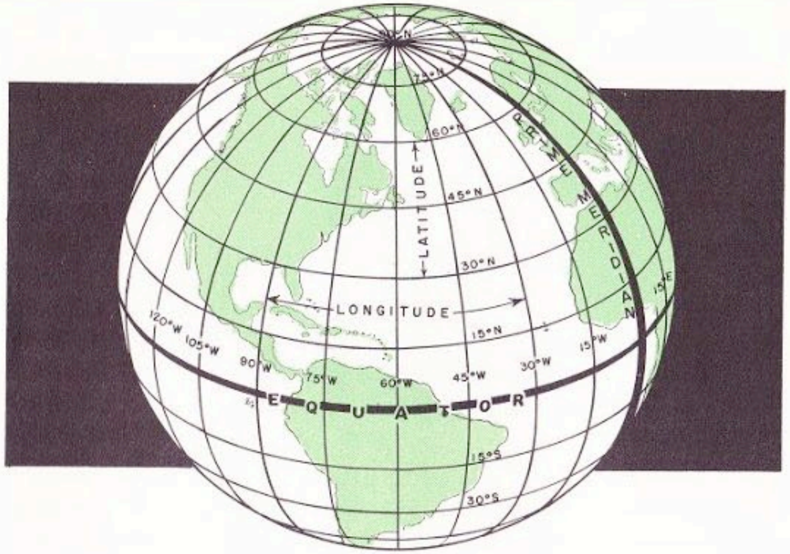
One way to keep an aircraft on its course is by reference to visible landmarks which are known to mark the desired flight path. This type of navigation is called *piloting* or *pilotage*. Another type is to calculate a compass heading in advance of the flight, then keep a careful record of the direction, distance, and time of flight between positions along the course. In this type of navigation, called *dead reckoning,* compass headings may have to be changed from time to time, during flight, in order to compensate for the effect of the wind and keep the aircraft on course.

Proper radio equipment enables the pilot to take advantage of the network of four-course ranges, and omni-ranges that mark the designated airways covering the country. (See *Airports, Airways, and Electronics,* Chapter V). This type of navigation is called *radio navigation*. Navigators skilled in the procedure can determine the position of a ship on the water or an airplane in the air by means of observing the position in the heavens of the sun, stars, or planets. This type of navigation is called *celestial navigation*.

One type of navigation is generally used in conjunction with another. The longer the flight, the more likely that several navigation methods will be employed. On flights across the ocean, celestial navigation plays its greatest role. Although some intercontinental flights, like that of Lindbergh from New York to Paris, have been by piloting and dead reckoning, today, navigators and pilots on such flights are likely to employ all four navigation types.



CHAPTER TWO



II. MEASURING TIME, DISTANCE, AND DIRECTION

Everyone who has studied elementary science knows that the earth moves around the sun in an elliptical path known as the *earth's orbit.* We all know that, it also revolves on its axis once every 24 hours. An interesting fact about this axis is that it tilts about 23½ ° in relation to the plane of the earth's orbit. This circumstance accounts for the change of seasons as the earth follows its yearly path around the sun. Of special interest at this time, however, is that the ends of the earth's axis, called the poles, provide us with convenient points upon which to build a system of measurements.

Meridians of longitude and parallels of latitude.

Midway between the poles is the Equator. It is an imaginary line formed by a plane[1] intersecting (cutting through) the exact center of the earth perpendicular to another plane intersecting the poles. The Equator is the only great circle[2] which can be perpendicular to a plane inter-

[1] As used in mathematics, the term, *plane,* is defined as a surface having length and breadth, but not thickness. Although a thin sheet of paper is actually a solid, because of its thinness, it may be used to illustrate the mathematical concept of a plane.

[2] A great circle of the earth is a path described on the earth's surface by a plane passing through its exact center, as the Equator or any Meridian of Longitude.

secting the poles. However, any number of planes defining great circles can be constructed perpendicular to the plane of the Equator and still intersect (or contain) the poles.

The circles around the surface of the earth defined by constructing such planes are called *meridians of longitude;* other circles around the earth which parallel the Equator are called *parallels of latitude.* In order to use meridians and parallels to indicate position on the earth's surface, reference points are chosen. These are provided by the *prime* meridian which passes through Greenwich, England, and the Equator.

Since meridians and parallels are circles, and circles are usually divided into 360 parts called degrees, we speak of Lat. 45° N. or S. and Long. 90° E or W. *The degree used in this way is a unit of angular measurement.* The angular distance from the Greenwich meridian around the world and back is 360°. Since points from Greenwich are measured up to 180° east or west, no point can be at an angular position from Greenwich of more than 180°. Likewise since the angular distance from the Equator to either pole is 90° (¼ rather than ½ of 360°), no point can have a latitude position greater than 90°. The position of any place on the surface of the earth can be expressed in degrees longitude and latitude. The position of New York City, New York is approximately Lat. 40° N., Long. 74° W. The position of Sydney, Australia is approximately Lat. 30° S., Long. 150° E.

As an hour is divided into minutes and seconds, an angular degree can also be divided into minutes and seconds. A minute in this instance is one-sixtieth (1/60) part of an angular degree; a second, one sixtieth (1/60) part of an angular minute.* Using angular minutes and seconds in addition to degrees, make it possible to locate the positions of places upon the surface of the earth quite accurately.

The time belts.

Everyone knows that a day is defined as the length of time it takes for the earth to make a complete revolution. During each revolution any point on the earth's surface will travel a circular path of 360°. Since there are 24 hours in a day, in one hour such a point will travel 360°/24 or 15°.

Since noon is defined as the time of day at which the sun is directly above a meridian, twelve o'clock noon (and consequently every hour

* Although a statute mile is 5,280 feet, a nautical mile is 6,080.2 feet (1853.3 meters). The nautical mile is 1/60 of a degree of the earth's equator (one minute).

of the day) *sun-time* differs for every meridian. The sun crosses these only one at a time.

As a result of these circumstances and the confusion that would otherwise result, it has become common practice to establish time belts for each 15° of longitude, each having a difference in time of one hour between them. Since the United States lies between 67° and 125° west longitude (Long. 67° W. and Long. 125° W.), the angular distance across it is 125° — 67° or 58°. Consequently, it is found convenient to divide continental United States into four time belts—Eastern, Central, Mountain, and Pacific. When the sun lies above Long. 75° W., it is noon Eastern Standard Time (1200 hours) throughout the Eastern Time Belt; 11:00 A.M. Central Standard Time (1100 hours) throughout the Central Time Belt; 10:00 A.M. Mountain Standard Time (1000 hours) throughout the Mountain Time Belt; and 9:00 A.M. Pacific Standard Time (0900 hours) throughout the Pacific Time Belt. As the sun crosses Long. 90° W., it becomes noon throughout the Central Time Belt with corresponding time changes within the other three time belts. Noon occurs throughout the Mountain Time Belt when the sun crosses Long. 105° W.; and throughout the Pacific Time Belt, when the sun crosses Long. 120° W.

You will discover that the dividing lines between the time zones sometimes are irregular and do not coincide exactly with the appropriate meridian. These irregularities result because communities near time-belt boundaries find it convenient to use the time schedule of a neighboring trade center.

Map projections and aeronautical charts.

The great problem of map and chart making (cartography) is to represent the spherical surface of the earth on a flat map or chart so that positions may be fixed and distances measured accurately. If you have ever tried to flatten the cover of a baseball, you know how difficult is the task of the map maker (cartographer). The ideal map, which has never been realized, would be of true shape (conformal), true size (equal area) and true direction (azimuthal).

Cartographers have devised a number of methods by which they solve (for all practical purposes) this problem. Obviously the purpose for which a map or chart is to be used determines to some extent the method of its construction. Three projections or methods of map making are most commonly practiced. These are the *cylindrical,* the *conic,* and the *gonomonic* projections.

Imagine a transparent globe of the earth, including its geographical figures and lines of longitude and latitude, with a lighted electric light bulb in its exact center. If a rectangular sheet of paper is wrapped around this globe so that it forms a cylinder, the light will cause the areas and lines of the globe to be projected on the cylinder. If these areas and lines are traced on the paper and the paper unrolled, a cylindrical map projection will result.

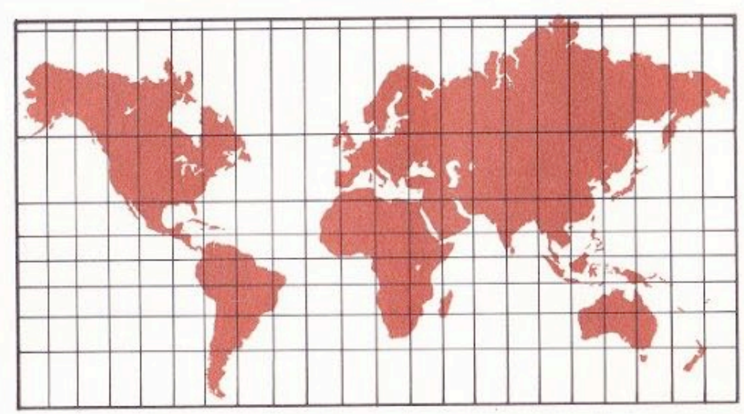
If a paper cone is placed over this globe and the projected areas and lines traced on the paper, the result will be a conic projection. If a circular sheet of paper is placed tangent to (touching) the globe, and the projected areas and lines traced on the paper, the result will be a gonomonic[1] projection. A comparison of these projections with the globe will show that in each projection there are certain distortions.

The Mercator Map.[2]

The most noticeable characteristics of the Mercator Map are (1) the meridians are vertical, (2) the parallels horizontal, and (3) that the separation of these increase as they approach the poles. Although the Mercator projection shows the true shape of each area (is conformal), it does not represent each in proper proportion one to another (is not an equal area projection). Neither is the mercator a true direction projection (does not show the true bearing or *azimuth* of one place from another).

[1] Gonomonic (pronounced no-mon' ik) means "that which knows". It shows true direction. Its use is in long range flying.

[2] The Mercator Map was devised in 1569 by a Fleming (a Northern Belgian) Gerhard Kramer, who called himself Mercator.

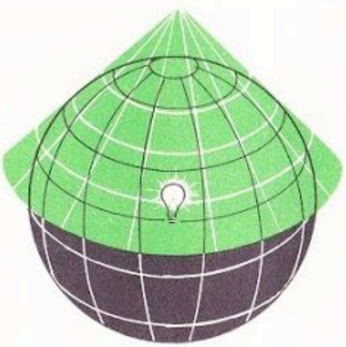


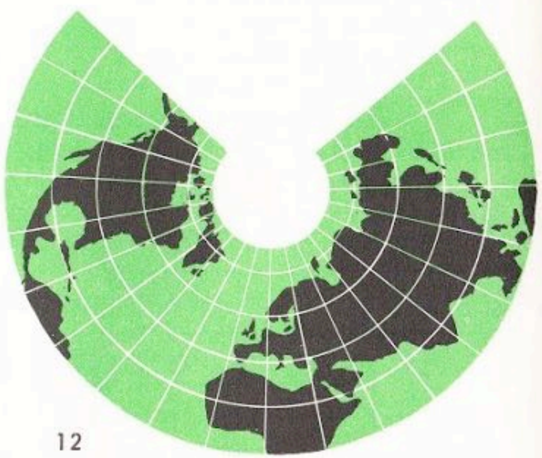
The chief advantage of the Mercator is that it shows true compass direction. A straight line drawn between any two points on this projection will show the constant compass course between them (see page 11). This line is called the rhumb line. A line drawn on a globe so that it crosses each meridian always at the same angle in order to maintain a constant direction would assume the shape of a spiral curve (loxodrome). Obviously a rhumb line is not the shortest distance between two points on the surface of the earth. A great circle route is the shortest distance between two such points. However, when the magnetic compass is used as the direction finder, the only way the navigator can follow a great circle route is to plot his course as a series of short rhumb lines. (See page 13.)

The Lambert Conformal Conic Projection.

The Lambert Conformal Conic Map or Chart is projected on a cone which intersects the globe on two parallels of latitude. It shows the true shape of areas between the parallels, but only on the two parallels are areas accurately represented. Between the two parallels, the areas are somewhat smaller than those on the globe; outside the parallels, somewhat larger. However, the scale error is always small.

Meridians and parallels intersect at right angles on the Lambert Chart and their relationship with those on the globe are always constant for all directions. You will observe that parallels of latitude appear on the Lambert Chart as curved lines.



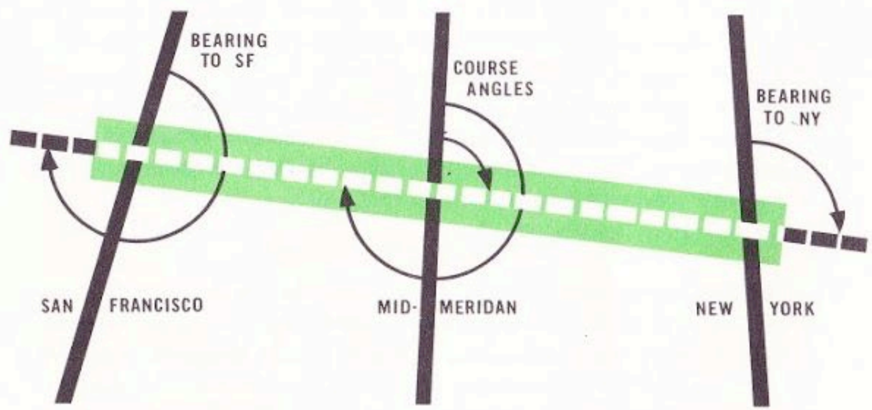


On the Lambert Map or Chart, a great circle may be represented by a straight line. The maps prepared by the U. S. Coast and Geodetic Survey to meet the needs of aerial navigation use the conformal conic projection. Both Sectional Charts and World Air Charts represent small sections of larger areas. Such charts fit together accurately. Each contains a wealth of aeronautical data pertaining to course plotting and navigating.

The true course.

Directions on a chart are measured in angular degrees, minutes, or seconds. The bearing (direction) of one place from another is always measured clockwise from North. Hence a place due east of you would bear 90°; one due south, 180°; one due west, 270°. If you measure the angle formed by the line drawn on the chart and the meridian of your position, you will find the direction or bearing of the place to which you want to go. However, on the aeronautical charts in common use, the line you have drawn will not cross all meridians at the same angle. If you wanted to fly from New York to San Francisco, and measured the bearing of New York on an aeronautical chart, you would find it to be 282°. However, if you take a bearing on San Francisco from the Meridian half way along your course line, you will find this to be 265°. It is a common practice to break up long flights into legs of 3° or 4° of longitude, and to measure the angular direction of each leg at its mid-meridian.

Measuring the True Course



Measuring a true course (TC).

It is quite easy to find the direction of the course to be followed in flight. A line is drawn from the point of departure to the destination of the flight. Then a measurement is taken of the angle this line makes with the meridian midway between these points. This measurement is the *true course* (TC) direction. It is not necessarily the direction (TH) toward which the nose of the airplane is pointed in order to offset the effect of the wind and make good the TC.

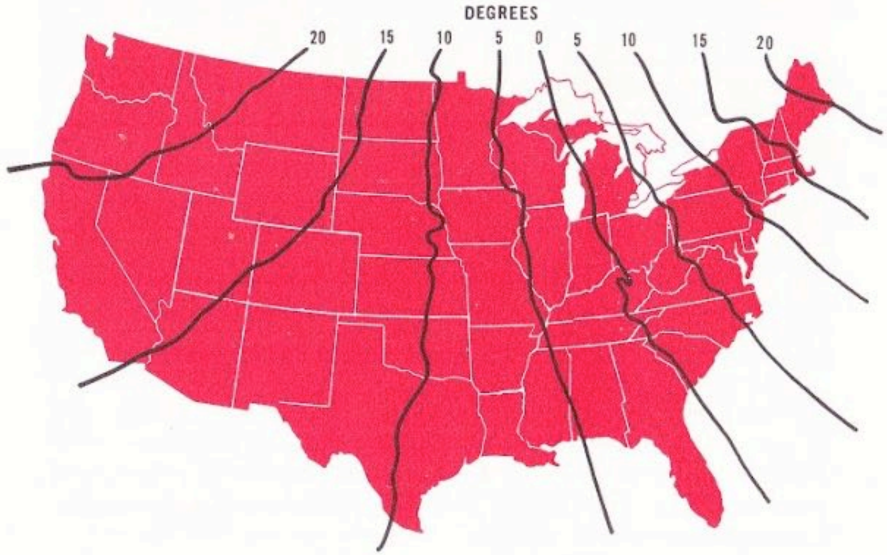
The compass rose printed on the aeronautical chart may be used to measure course direction. An instrument called a protractor or one called a plotter which incorporates a protractor serves this purpose even better than the compass rose. Both the compass rose and protractors are marked off in degrees (units for measuring direction).

If the difference in longitude between the points of departure and destination is not more than 3° or 4°, the course should be measured at its mid-meridian. If the difference in longitude between this point is greater than 4°, then the course should be divided into a series of courses, each crossing not more than 4° of longitude. In this latter instance the true course (TC) direction of each course-segment will become the basis for the heading of the aircraft during its flight along such course-segment.

In order to measure the direction of a course or course-segment, the protractor should be placed with the mid point of its base at the intersection of the course line and the mid-meridian and its 360° mark (N) on the mid-meridian. Since a course is measured clockwise from N, read the direction in degrees on the curve of the protractor where it is intersected by the course line. You will observe that should a course be in the direction of 40°, the return course would be in the direction of 220°. Should it be in the direction of 192°, the return course would be in the direction of 12°. There is always 180° difference between a course and its reciprocal (return course). To find the reciprocal of a course less than 180°, one must add 180°. To find the reciprocal of a course 180° or greater, one must subtract 180°.

Magnetic meridians and magnetic courses.

The true course when there is no wind blowing is the true heading of an aircraft in flight. However, there is generally a variation between the true heading and the heading indicated by the magnetic compass. This condition exists because the magnetic poles do not coincide with the poles defined by the earth's axis. The north magnetic pole is



Magnetic Meridians

located near Lat. 71° N., and Long. 96° W., about 1300 miles from the geographic north pole.

On aeronautical charts the degree and direction of magnetic variation are shown by magnetic meridians called *isogonic* lines. Such lines connecting points of equal magnetic variation, are likely to be irregular, and extend from the north to the south magnetic pole. Points at which there is no magnetic variation are joined by a line called an *agonic* line. Isogonic lines show the general direction toward which a compass needle will point.

At San Francisco, the variation is 18° E. Since this means that the compass needle points 18° East of true north, a pilot, to fly a true heading* of north in the San Francisco area, must fly a magnetic heading of 342° (360° — 18°). To find the magnetic course corresponding to any true course in the San Francisco area one must subtract 18° from the amount of the true course. To fly east in this area, a pilot must use a magnetic course of 72° (90° — 18°). To fly a true course of 118°, he must use a magnetic course of 100°.

At New York, the variation is 11° W. Since this means that the compass needle points 11° west of true north, a pilot, to fly a true heading of north, must fly a magnetic heading of 11° (0° + 11°).

* All heading calculations used are based upon a "no-wind" condition.

To find the magnetic course corresponding to any true course in the New York area, one must add 11° to the amount of the true course. The pilot remembers that to convert true direction to magnetic direction, he must note the variation shown by the proper isogonic line on his chart. If the variation is east, he must then subtract the variation from the true direction; if it is west he must add the variation to the true direction.

The basic navigation instruments.

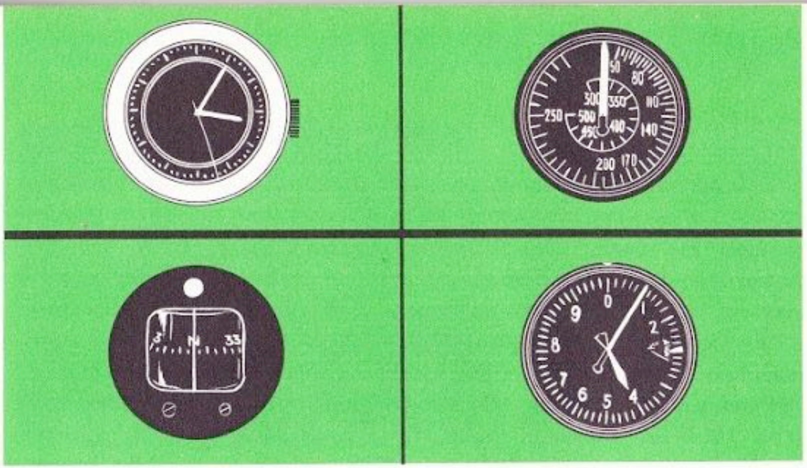
As aviation develops and aviation activities become more complex, new navigation instruments are developed. The modern aircraft used in military or air transport operations employ many navigation instruments. However only four of these are indispensable in piloting and dead reckoning. These are the *clock*, the *air speed indicator*, the *magnetic compass*, and the *altimeter*.

The *clock*, or watch, is used to measure the elapse of time between check points. Hence, it is essential when a pilot wants to learn the ground speed of his airplane in flight, estimate arrival time, and compute fuel consumption. The potential energy of a coiled spring operates the mechanism of the clock, or watch; uniform speed of operation is obtained by means of a balance wheel.

The *airspeed indicator* is used to measure the speed of the aircraft through the air. (Not its speed over the ground.) Its operation depends upon the difference between the pressure of air in motion, as registered by the pitot tube, and the air contained in the instrument case of the air speed indicator. (See *Aircraft in Flight*, page 51.) At any considerable altitude, since the comparative air density is low, the indicated airspeed reading is too low. True airspeed can be approximated by adding 2% of the indicated airspeed for each 1000 feet of elevation above standard sea level.

The *magnetic compass* is used to determine direction. Its operation is based upon the attraction that the earth's magnetic poles has for the compass needle. A compass card is attached to the needle. Excessive swinging of the compass card and needle is dampened by a light oil which fills the compass case.

The magnetic compass does not indicate true directions for three possible reasons: 1. A geographic pole and its corresponding magnetic pole are not at the same place. 2. Local ore deposits influence com-



Basic Navigation Instruments

pass action. 3. The engine and other aircraft parts and equipment affect compass operation.*

A directional gyroscope is often used with a magnetic compass. It employs the principle of gyroscopic inertia. Gyroscopic inertia means that a gyroscope, as long as its wheel is revolving, tends to remain in the same position and plane of rotation—that is, regardless of the heading the aircraft assumes, it tends to keep its original direction. It is more accurate than a magnetic compass during turns in flight, but because of precession (a tendency to advance), it needs to be reset at fifteen minute intervals.

The *altimeter* measures altitude. Its operation is based upon the fact that as altitude increases air pressure decreases. The variations in the air pressure upon a hollow sealed diaphram activates an indicator needle. This needle records pressure altitude as feet above sea level. To obtain exact altimeter readings the indicated reading must be corrected for current atmospheric pressure and temperature conditions. Altimeters read correctly only when sea level temperature is 59°F. and the temperature decrease per each 1000 feet of altitude is 3.6°F. It also takes the altimeter a few seconds to record changes taking place in an aircraft's elevation. This charactristic is called altimeter lag.

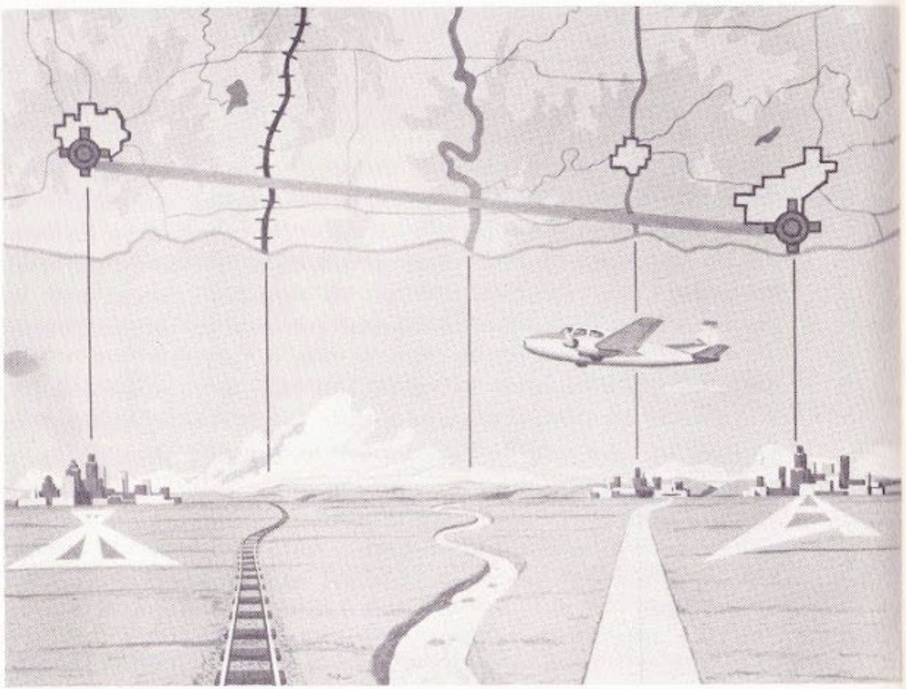
Reading a chart.

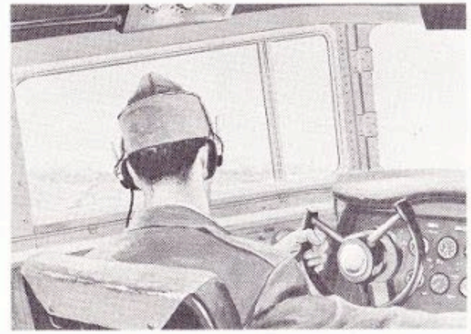
You have already learned that the chart used in air navigation contains much important information. Some of this information deals with landmarks which the pilot uses to check his position. Some of this information helps the pilot when he is planning his course.

* A compass correction chart is placed in the cockpit of every aircraft to show the compass deviation for such aircraft.

In order to indicate landmarks, such as cities and towns, highways, railways, rivers, swamps, mines, lookout towers, and the like, standard symbols are used. (See illustration below.) In order to indicate *topography* (the size, shape, and position of features of the earth's surface), contour lines and colors are used. Contour lines are drawn so that each line passes through places, all of which have the same elevation above sea level. The closer the contour lines are together, the steeper the elevation. On the aeronautical chart, elevations from 0 to 1000 are shown in green; those from 1000 to 2000, in light green. Elevations from 2000 to 3000 are shown in light brown. As elevations increase the shades of brown become increasingly darker. the points of highest elevation are marked by a small, black dot and a number designating its height in feet.

Reading the Chart





CHAPTER THREE

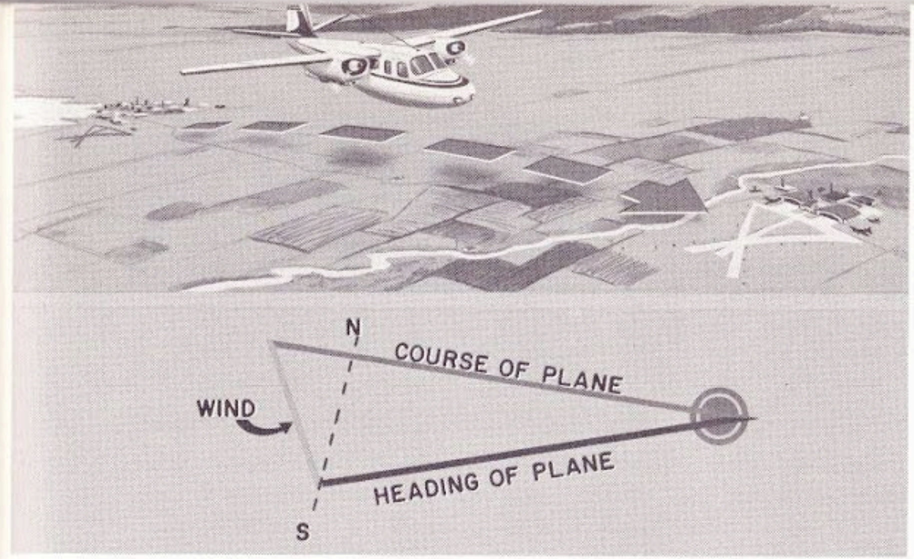
III. PILOTAGE

"Before take-off" navigation procedures.

It is common practice for pilots to plan their flights in advance. Should the aircraft a pilot is to fly have neither radio transmitter nor receiver, the flight planned will likely be navigated by means of pilotage, dead reckoning, or a combination of these two methods. In any of these instances, the aircraft must have a magnetic compass, an airspeed indicator, and an altimeter; and the pilot must have an accurate watch. If an aircraft has no radio equipment, it is restricted to visual flight rules (VFR) operations. Consequently, the planning of a flight under these circumstances must take VFR weather minimums into account.

The "before take-off" procedure undertaken by a pilot is the same, up to a point, for both pilotage and dead reckoning. 1. On the chart that he uses, the pilot draws a line from the location representing the point of his departure to that which represents his destination. This is the true course line, and its angular direction measured at its mid-meridian will give the direction of the true course (TC). See page 13.) 2. He "marks-off" the true course line in segments representing distances of 10 miles (when more convenient, other distances may be used). 3. He selects land marks along or near his route to use as "check points". The first of these should be a prominent land mark near the airport. However, it should be far enough from the airport, so that the aircraft before reaching it will have left the airport traffic pattern and reached its cruising altitude. These check points are used by the pilot to help ascertain the ground speed of his aircraft and to keep it on the proper heading. 4. He must now select suitable "brackets"* near enough to the course to be easily seen. Whenever

* A bracket is a terrain feature such as a railway, river, or prominent highway which parallels a course, or a portion of a course.



Pilotage

possible, brackets should be indicated along both sides of the course line. End brackets should also be marked. These help prevent "over-flying" the airport of destination. 5. The pilot next measures the direction of the true course. (See page 13.) 6. The pilot finally finds the compass course by taking into account both magnetic variation and compass deviation.

A flight by pilotage.

If you are a pilot planning to navigate a flight by pilotage and have completed these six steps you are ready to begin your flight and to follow the steps of procedure required by the in-flight phase of Pilotage: 1. As soon as your aircraft leaves the airport and reaches the first check point, place it on the proper compass course. 2. Observe the direction in which the wind is drifting your aircraft, using the drift meter if your aircraft is equipped with one. 3. Correct the heading so that the aircraft's direction as determined by your reference points corresponds to that of the TC line. 4. Note the elapsed time between your first and second check points and determine your ground speed. 5. Keep a continuous check on the position of your flight by means of check points and brackets.

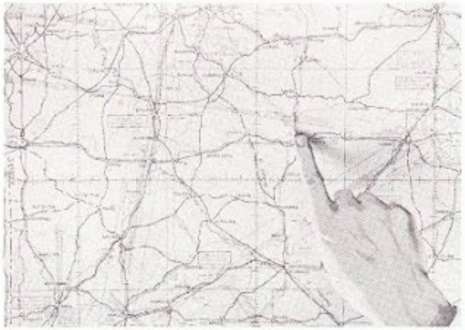
Assume that you have just completed a flight from Bowman Field at Louisville to Cincinnati-Lunken Airport navigating by pilotage. Before beginning the flight you found your magnetic course to be 47°. However, the compass correction chart in the cockpit of your aircraft reads as follows:

For	(MH)	N	30	60	E	120	150	S	210	240	W	300	330
Steer	(CH)	0	29	57	86	117	149	180	211	243	274	303	334

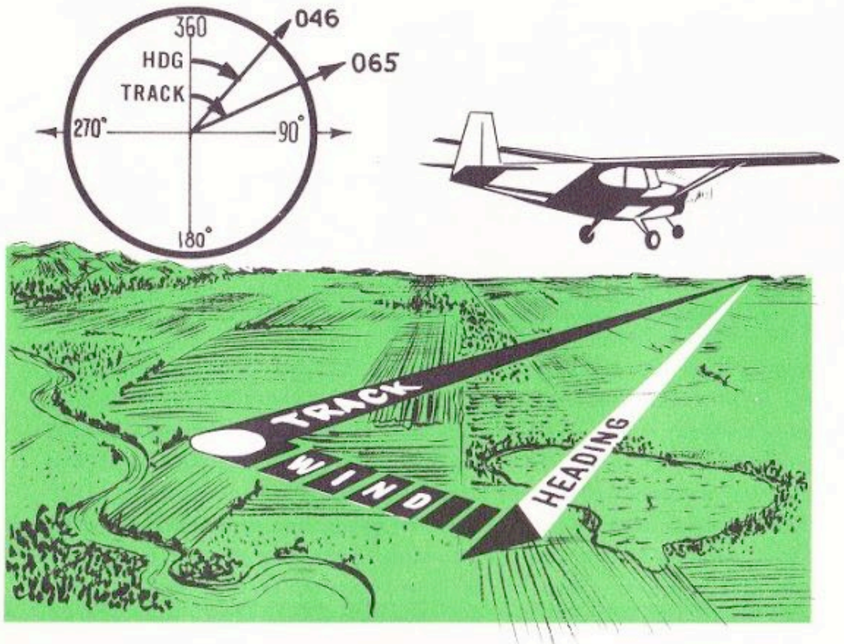
Consequently, after you left your first check point, you headed your aircraft toward 45° (47° — 2°).* Had your flight from Louisville to Cincinnati been an actual rather than an assumed one, a report of your subsequent experience could have been quite similar to the following:

1. As you passed your first check point after leaving Bowman Field, you checked your watch and observed the hour to be 10:00 a.m. At 10:10 you found that the position of your aircraft was over a railway, 2 or 3 miles on the right of your course line. You also observed that your position was about midway between two towns, which you identified as Pewee Valley and Crestwood. You rightly concluded that the wind had drifted you off-course and that you should correct your heading. Consequently, you changed your compass heading (CH) from 45° to 43°, assuming that such an amended heading into the wind would put you over La Grange after a further time elapse of four or five minutes. However, at 10:15 you discovered La Grange on your left, and that the wind was still drifting your aircraft off course to the right. Consequently, you made still another CH correction. You now aligned your aircraft on a CH of 38° with landmarks which, according to your chart, appeared to be on a new direct course from your present position to Cincinnati-Lunken Airport. At approximately 10:24 a.m. your position was directly over Campbellsburg, one of these landmarks. You held a heading of 38° for the next ten minutes and discovered that you were exactly on course. You reached Cincinnati-Lunken Airport at 11:05 a.m. and circled the airport, landing after you got a green light from the control tower.

* In order to determine the CH (45°) it is necessary to interpolate (determine average). MH47° lies approximately half way between 30° and 60°. The compass heading correction necessary lies between 1° (MH30° — CH29°) and 3° (MH60° — CH57°). The average therefore is approximately 2°; hence (47° — 2°) = 45° CH.



CHAPTER FOUR



The Wind Vector Diagram

IV. DEAD RECKONING

A pilot using dead reckoning to navigate the course from Bowman Field to Cincinnati-Lunken Airport, would have taken an additional step in his "before take-off" procedure. He would have converted the magnetic course to a magnetic heading by taking into account the effect upon his aircraft of both wind speed and direction. In order to do this, he would have ascertained from Pilot Information Service or the Weather Bureau the wind conditions which prevailed. This done, he would have used the wind speed and direction factors to calculate his compass heading, ground speed, time of arrival and the amount of fuel needed for the flight.

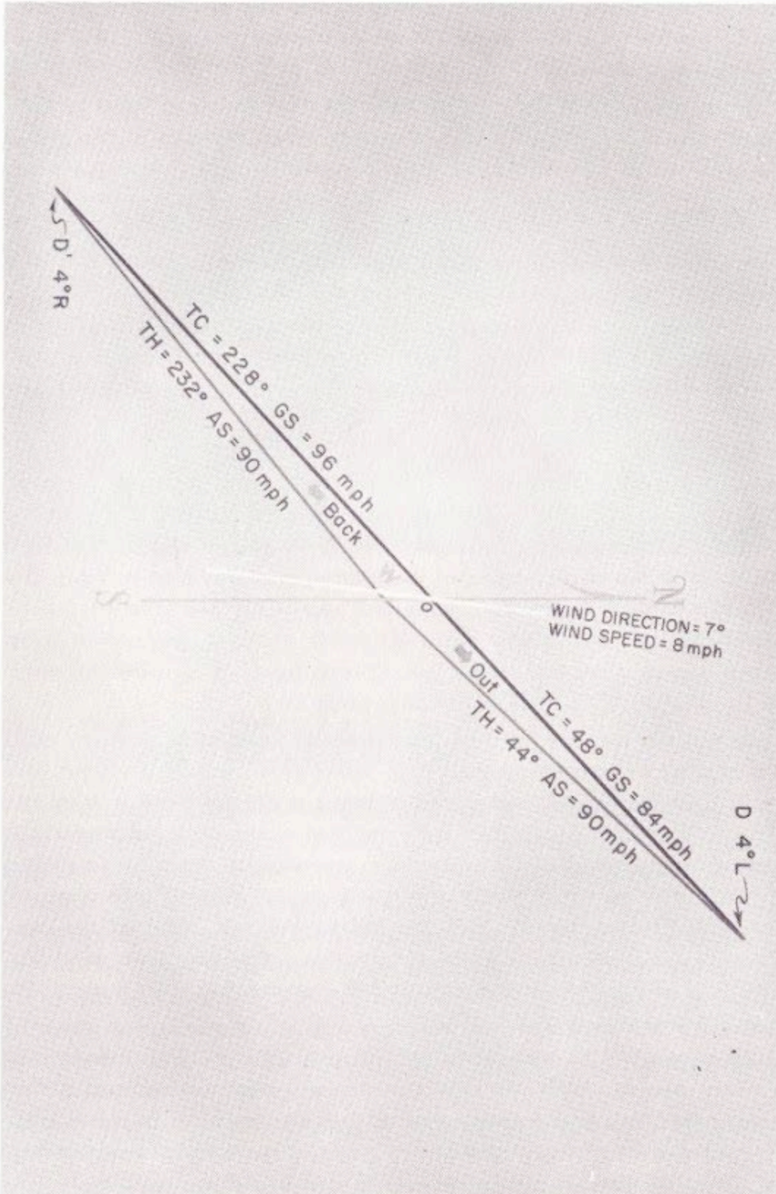
You remember that a heading is a course corrected for wind effect. By drawing a wind triangle (or by using a computer) both the proper *wind correction angle* and the *ground speed* of the aircraft in flight

may be found. It is necessary, however, that the airspeed of the aircraft, the true course it is to follow, the wind speed, and the wind direction be known.

If you measure the true course direction from Bowman Field to Cincinnati-Lunken Airport you will find that its direction is 48°. You know the speed of your aircraft to be 90 m.p.h. Information concerning wind conditions discloses that the wind is 8 m.p.h. from 7°. You now take a plain sheet of paper and draw a vertical line upon it, representing a north-south direction. Using a scale and a protractor, or a combination of the two called a plotter, draw a true course line in the direction of 48°. To do this you place the base of the protractor or of the protractor portion of the plotter along the vertical line just drawn, so that the protractor circle faces east; place a dot which you label "O" at the midpoint of the protractor base and a second dot at 48°. Draw a line from "O" through the second dot. Now replace the protractor, keeping the midpoint of the base at "O" and mark a third dot at 7°. Place your scale so that it intersects this third dot and the dot at "O". Then draw a line from 7° toward "O". (The wind is from 7°.) Using the scale or the scale portion of the plotter, measure 8 units along this line and make a fourth dot. (One unit represents one mile per hour.) Label this dot "W". Now place the scale on "W" and adjust it so that it intersects the true course line 90 units from "W". Label this point of intersection "D". (See illustration, page 26.)

By placing the mid point of the protractor base at D, you can read the number of degrees in the angle ODW (4°). This is the *wind correction angle,* (WCA), and in this instance, since the wind is from the left, if its value is subtracted from the true course, the remainder will be the true heading. The true heading may also be found by extending the line WD until it intersects the north-south line and measuring its direction. To measure its direction, place the mid point of the protractor's base at this point of intersection. You can then read the direction of line WD at the curve of the protractor. This is your TH. You will discover it to be 44°.

By measuring the number of units in line OD, you can discover the ground speed in miles per hour that you will likely make good during your flight. You can estimate arrival time on the basis of this speed. If you know the rate at which fuel is used by your aircraft engine (since you already know the time which will elapse during your flight), you



can determine its fuel needs. For example, if you know that your engine burns 6 gallons of fuel each hour, that you have a distance of 240 miles to fly, and that your ground speed is 80 m.p.h., you can find the amount of fuel you need.

$$\frac{\text{(Distance}}{\text{(Miles per hour}} \times \text{ rate of fuel consumption.}$$

$$\text{Substituting } \frac{240 \text{ miles}}{80 \text{ m.p.h.}} \times 6 \text{ gallons of fuel per hour} = 18 \text{ gallons of fuel.)}$$

Solving the wind triangle problem made it possible to find a true heading. You know that to fly a true heading, it may be necessary to fly a compass heading (indicated heading) that may vary considerably from the true heading. This is because of magnetic variation and compass deviation. Some pilots use a planning chart similar to the following, upon which has been assembled the dead reckoning data needed on your flight:

Pilots' Planning Chart

Cruising Air Speed	TC	Wind Speed	Wind Direction	WCA	TH	VAR	MH	D	CH
From: Bowman Field									
To: Cincinnati-Lunken	48°	8 m.p.h.	7°	4°L	44°	1°E	43°	2°E	41°

GS	Time	Fuel Rate	Fuel Used
84 m.p.h.	1:05	6 gal/hr	6½ gallons

There are several types of dead reckoning problems that may be solved by the wind triangle method. For example, a round trip flight may be graphically represented by extending the line OD in the wind triangle problem (see illustration, page 26) toward 228° (TC on the return trip), placing the scale on W and adjusting it so that it intersects the 228° TC line 90 units from W. By converting the wind triangle problem into a round trip problem you discover that on the return trip, you add the 4° WCA to the TC to get the TH, and that your ground speed is greater than your airspeed (96 m.p.h.).

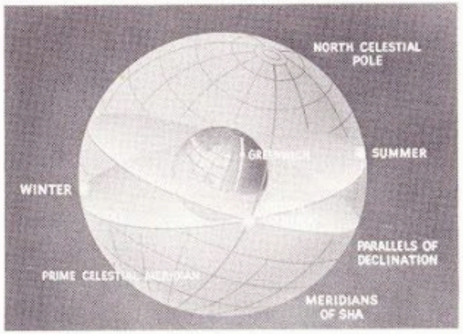
The wind-triangle problem, solved by the graphic method, is actually a *vector* problem. A vector has both force or velocity and direction. It may be represented by a line. In the simple wind triangle problem, the magnitude and direction of two vectors (lines) are used to find a resultant (another line). One vector represents the airspeed and TH of the aircraft; the other, the speed and direction of the wind; the resultant represents the TC and ground speed of the aircraft. Had the values of the resultant and one vector been known, the values of the other vector could have been found. For example when one knows the aircraft's airspeed and true heading and its groundspeed and true course he may find the wind velocity and direction which affected its flight.

There are a number of special navigation problems based upon the wind vector diagram (wind triangle) that commercial and air transport pilots should know how to solve. Sometimes a pilot knows his true heading (TH), air speed (AS), and wind conditions, but needs to discover his true course (TC), and ground speed (GS). Applying the principle of the wind triangle problem makes possible the prompt solution of this problem.

Sometimes a pilot knows his TC, TH, GS, and AS and wants to learn the wind direction and velocity. In this instance he simply supplies the wind vector, measures its length which gives him wind speed, and its direction which is the same as the wind direction.

Sometimes a pilot has only his air speed and drift angles on two directions to find the wind velocity and direction. Essentially, the solution of this problem depends upon the construction of two wind triangles in combination. The wind vector will be common to both. Its measurement will give the desired information.

Problems such as these and *off course problems* are solved by employing the principle of the vector diagram. Computers provide one with a convenient way of doing this. However, to acquire skill and exactness in the use of the graphic diagram or the computer requires practice. Until such time as you need to use these skills in practical situations, it is sufficient that you understand in a general way their method and importance.



CHAPTER FIVE

V. RADIO FLIGHT AND CELESTIAL NAVIGATION

The use in navigation of instruments based upon the principles of radio and electronics is becoming increasingly important. Of the four types of navigation, radio alone is virtually independent of the weather. Moreover, modern aviation is coming to depend increasingly upon the airport and airway facilities based upon recent tremendous advances in radio invention. (See *Airports, Airways, and Electronics.*)

However, before an aircraft can take advantage of some of aviation's electronic aids, it must be properly equipped, and such equipment is expensive. Yet, the advantages of radio flight so overshadows such a disadvantage that most of today's aircraft are provided with a radio receiver-transmitter.

In order to use the four-course radio-range signal for the purposes of navigation, an aircraft needs to be equipped only with a radio receiver and antenna. Although this equipment is simple, the navigational procedure it requires is rather complex. Also, its operation takes considerable pilot skill and time. More complex equipment actually requires less operational skill and time.

The four-course radio range in navigation.

You know that it is possible to control the direction of radio waves by transmitting these from a loop or a rectangular antenna. The strong signal will emanate from the long sides of the antenna; and virtually no signal is broadcast in the plane at right angles to the long sides of the loop. This makes possible the use of two loops, each bisected at a

right angle by the other, as a course marking device. One loop broadcasts an N (— -) signal in one direction; the second broadcasts an A (- —) signal in the other. The broadcasts are so spaced that in the areas of least signal strength where the signals overlap no letter signals can be detected, only a steady "hum" is heard by the pilot.

The pilot can fly this "hum" or "beam" directly to a radio range station. However, occasions may occur when he gets "off the beam." Under such circumstances he logically wants to return to his course. To do this, he must (1) identify the quadrant (one-fourth part of a circle, in this case one of the two areas into which either the signal A or N is broadcast); (2) locate the beam; and (3) make sure he is headed in the proper direction along the beam.

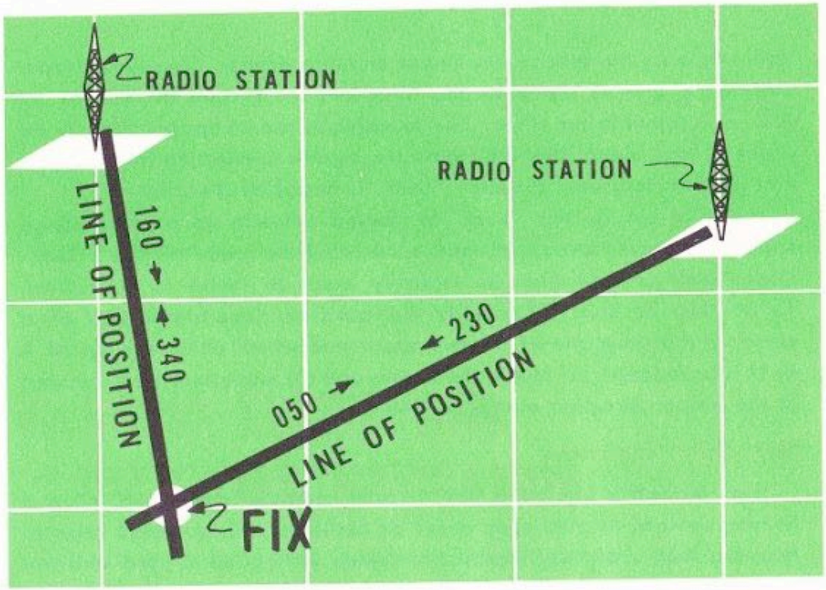
The radio compass.

If an aircraft is equipped with a radio compass (sometimes called a homing device), its pilot need never be bothered with quadrant orientation, but must make certain that his plane is headed toward and not away from the radio station. The radio compass is based upon the directional characteristics of the loop antenna. When the loop is at right angles to a station, the signals received are very weak. The loop antenna of the radio compass is fixed at right angles to the longitudinal axis of the plane, so that when the plane is headed either toward or away from the station only weak signals are received and the indicating needle of the radio compass points to zero.

The radio direction fiinder.

The radio compass uses a fixed loop antenna; the radio direction finder uses a rotatable loop. To use the radio direction finder, a pilot rotates the loop until he gets a null (no signal) through his headphones. Rotating the loop also turns an indicator on the scale of the direction finder. Consequently, when the pilot gets a null through his headphones, he can read on this scale the bearing of the station from his aircraft. By taking bearings on two separate stations and drawing lines of position in the direction of the reciprocals of these, he can locate a fix. The fix is at the intersection of two lines of position plotted on an aeronautical chart and gives the pilot the position of his aircraft.

It is current practice to use radio navigation instruments in conjunction with one another and with other more basic navigation instruments. It is likely, however, that VOR, DME, The Course Line Computer,



The Radio Fix

and other similar devices eventually will render obsolete some of the radio navigation devices and techniques now in use. (See, *Airports, Airways, and Electronics*, pages 32-35.)

Celestial navigation.

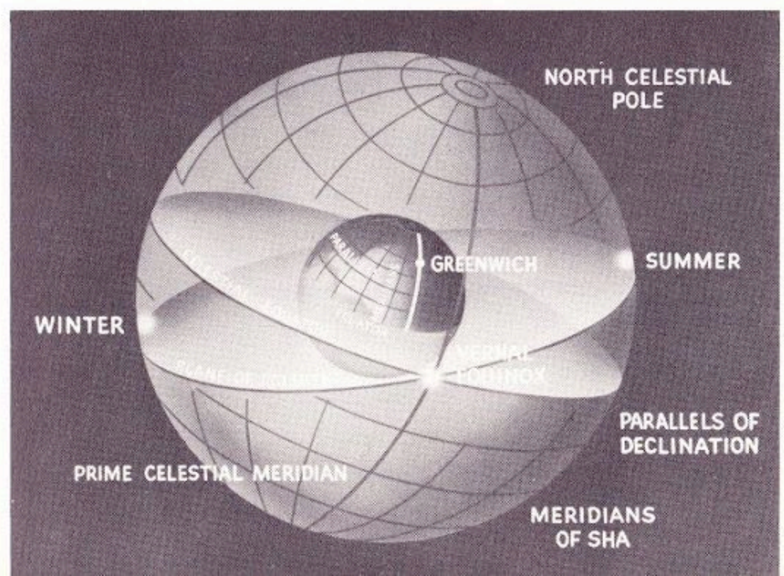
As the term celestial navigation implies, the stars in the heavens are used as points of reference by the navigator. As one looks into the sky at night, the heavens appear as a hemisphere studded with stars. The stars are so far away that they all appear fixed and at an equal distance from the earth. In fact, the navigator must assume that such is the case, that each star has a definite position on the surface of a *celestial sphere*, and that this sphere encloses the earth (the *terrestrial sphere*).

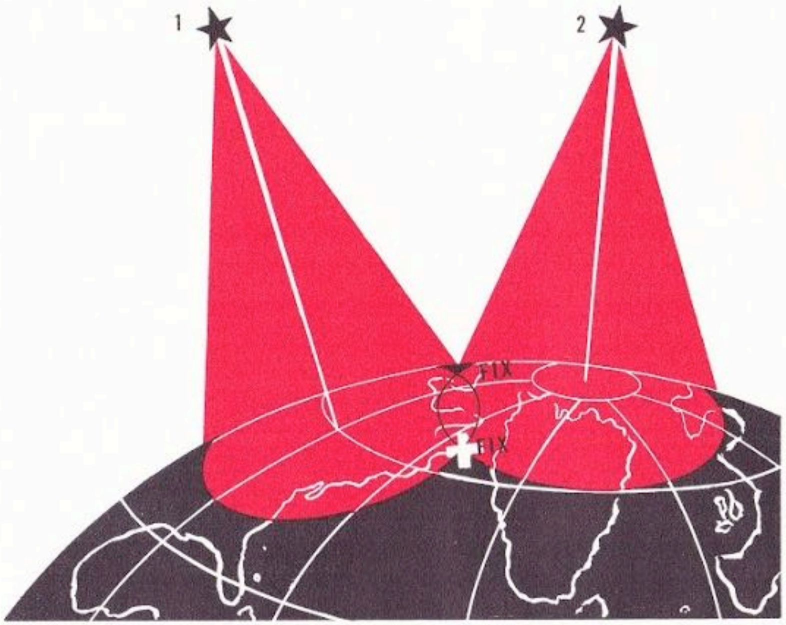
Celestial coordinates.

Just as the position of cities are fixed upon the surface of the terrestrial sphere by means of coordinates called meridians of longitude and parallels of latitude (see page 9), the position of the stars on the celestial sphere are fixed by means of coordinates. Just as the north and south pole and the equator of the terrestrial sphere (the earth) are used as reference points for establishing meridians of longitude and parallels of latitude, the north and south celestial poles (extensions of the terrestrial axis) and the celestial equator (extension of the plane of the terrestrial equator) are used as reference points for the celestial coordinates.

The celestial coordinates corresponding to the parallels of latitude on the terrestrial sphere are called *parallels of declination* and are measured in degrees north or south of the *celestial equator*. Those corresponding to the meridians of longitude on the earth's surface are called *meridians of the sidereal hour angle* (SHA). The SHA is measured only westward from the *prime celestial meridian*. The prime celestial meridian is a great circle passing through the north and south poles and the *vernal equinox*. The vernal equinox is that point at which the plane of the *ecliptic* crosses the celestial equator. (This is called the first point of Aries, the ram; it is symbolized by the sign of the ram's horns.) The ecliptic is that plane, assumed to pass through the center of the sun, which contains the orbit of the earth; consequently, it is the apparent path of the sun.

Celestial Coordinates





Circles of Position

Circles of position.

Each star has, at any given time, some point on the earth's surface which is directly beneath it. This point is called its *substellar* point. At this point the star is said to be at its zenith (directly overhead), and the angle formed by a line from the star to this point and a line from this point to the horizon is 90°.

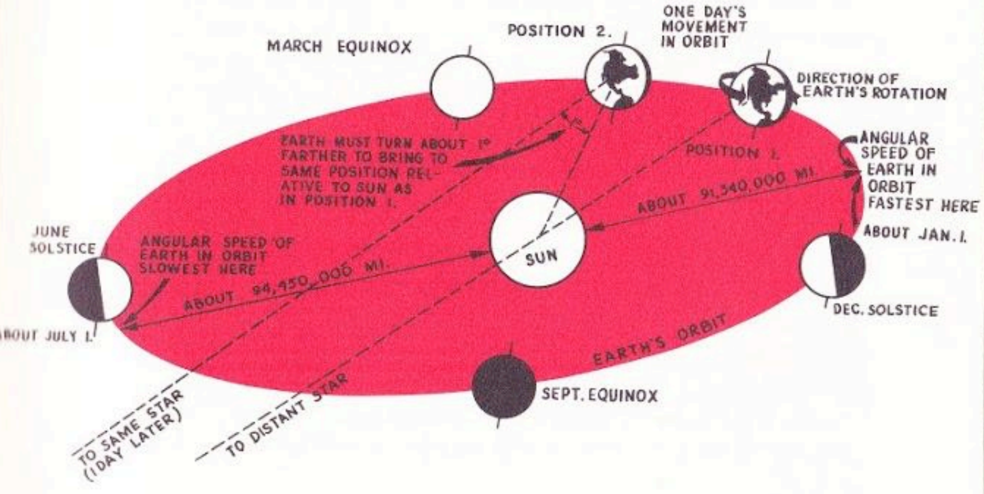
When an observer moves away from the substellar point, the angle formed by a line drawn from his position through the substellar point toward the horizon, and one from his position drawn toward the star will be less than 90°. With the substellar point as the center any number of concentric circles may be drawn. At any point on each circle the altitude of the star (the angle formed by lines from star to observer's position, to horizon) is the same. Such circles are known as circles of position.

If the coordinates of the earth and those of the celestial sphere always matched each other, each star would always have the same substellar point on the earth's surface. If this were the case, it would be a comparatively simple task for a navigator, skilled in the use of the instruments of celestial navigation, to find his position.

The observer would find the altitude of two stars and draw a circle of position for each. Or rather, he would draw only segments of these circles on the chart area which he knows to encompass his generally known position. The point of intersection of these two lines of position, under such circumstances, would disclose his position (a fix).

Since the earth is revolving constantly, not only upon its own axis but also around the sun, the procedures of celestial navigation include other steps than those outlined above.

The Problem of Time



The problem of time.

Because of these movements of the earth, the celestial navigator discovers that he must be concerned with both a solar (sun) day and a sidereal (star) day. Just as the solar day is measured from the time it takes the sun to leave a point in the heavens and return to that point, a sidereal day is measured from the time it takes a star to leave a point in the heavens and return to that point. Because of the movement of the earth in its orbit, the solar day is longer than the sidereal day. The difference between the length of solar and sidereal day affects the daily position of a star's substellar point.

The celestial navigator's reference sources.

When a navigator knows the position of the Greenwich meridian with respect to the prime celestial meridian, at the time of his observations, he can discover the substellar point of the stars in question. In order to discover this relationship he needs to use information published in the American Air Almanac[1] and a publication of the U. S. Hydrographic Office, known as HO 249, published in three volumes. These will provide data needed to solve problems of celestial navigation.

The celestial navigator's instruments.

In addition to these indispensable sources of reference, the celestial navigator must use two instruments without which he cannot locate his position. One of these is a *chronometer* (a precise and accurate timepiece). The other is an instrument which measures the altitude of a star. As a general rule, marine navigators use a *sextant*[2] for this purpose, while aerial navigators use a *bubble octant*[2].

Once a basic understanding of celestial navigation is acquired and the steps of its procedure learned, accurate celestial navigation depends upon the degree of skill developed by the navigator in the use of his instruments and books of reference.

The mathematical skills it requires are no more complex than those required in dead reckoning. Once the terms it employs are understood, much of its mystery is lost.

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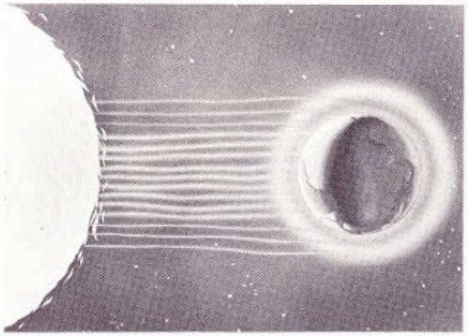
[1] Published four times each year by the U. S. Naval Observatory.

[2] A sextant refers to one-sixth of a circle; an octant to one-eighth of a circle.



CHAPTER SIX

VI. THE WEATHER

Just as the state of the weather is important to men who sail the sea, it is important to men who follow the paths of flight. For the wind and weather cause the conditions that complicate the tasks of pilots and navigators. Many of the rules of air traffic are made necessary because of the effects of these. Research and development in navigation aids have been stimulated by the need to operate aircraft under all types of weather conditions. The fact that the force and direction of the wind are elements of even the most simple problem of air navigation establishes the importance of the weather factor.

The atmosphere.

The atmosphere is the great ocean of air which surrounds the earth. Air, since it is a mixture of gases, has characteristics in common with other gases. It has weight, exerts pressure, and is compressible. (See *Aircraft in Flight,* page 8.) It is subject to the same gas laws or principles to which other gases are subject. (See *Power for Aircraft,* page 8.)

The mixture of gases which make up the air contains 78% nitrogen, 21% oxygen, and 1% several other gases. These other gases are carbon dioxide, argon, neon, helium, krypton, xenon, ozone, radon, hydrogen, and water vapor. Some meteorologists estimate the thickness of the atmosphere to be 600 miles. They think of it as divided into layers. The first layer above the surface of the earth is called the *troposphere.* (Troposphere means region of change. It is in this layer that most weather change takes place.)

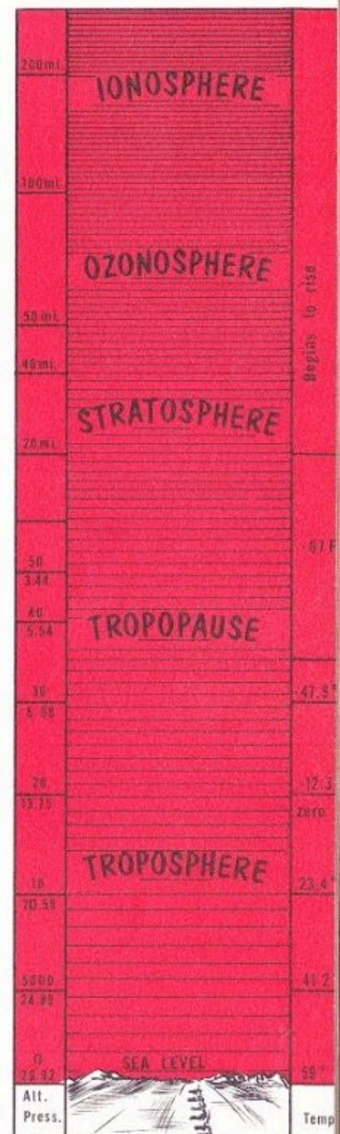
The second layer, called the *tropopause* is a thin layer separating the troposphere from a third layer, called the *stratosphere.* Above the stratosphere lies the *ozonosphere,* and the *ionosphere.*

At mid-latitudes the troposphere extends to an elevation of about 35,000 feet. Because air has weight and is compressible, the air at sea level is heavier than it is at any elevation above sea level. That is the weight of (the pressure exerted by) the upper atmosphere compresses the lower atmosphere, reducing its volume. We call this relationship between weight and volume by the term density. This relationship can be shown by the formula: $\text{Density} = \frac{\text{weight}}{\text{volume}}$.

We discover that with altitude, both the pressure exerted by the air (and consequently its density) and its temperature decrease. Under average conditions, sea level air has a pressure that will support a column of mercury (Hg) 29.92″ high and has a temperature of 59°F. At the 5000 foot elevation, its pressure has fallen to 24.89″ Hg; its temperature to 41.2°F. At the 20,000 foot elevation, its pressure has fallen to 13.75″ Hg; its temperature to —12.3°F.

The discoveries that the scientists, Boyle and Charles, made during the 17th and 18th Century revealed some important things about the nature of gases. One of the most significant of these discoveries was that the volume of a body of gas, its pressure, and its temperature are related. This means that when one of these essentials changes, the other two change. For example, when the temperature of an air mass rises, its volume increases (consequently its density decreases). Because of the relationships of these characteristics, when a mass of air of a given volume is heated its pressure increases, it expands, its density decreases, and it is displaced by surrounding air which is cooler and heavier. Both vertical movements called convection currents, and horizontal air movements called winds take place as a result of these changes.

This behavior, under certain conditions, of the gases that comprise the atmosphere is responsible not only for the wind but also for other weather phenomena. We have noted the changes that take place in gases when temperature changes take place. Temperature is a function of heat. Heat also causes the water of the earth's surface to evaporate (change its state from liquid to vapor). Warm air can contain a



The Atmosphere

greater amount of water vapor than cold air. Consequently, when air containing considerable amounts of water vapor reaches an elevation where the temperature is comparatively low, it is cooled. Its water vapor condenses. The condensation products—clouds, fog, rain—occur. Yet, before the balance of the troposphere is disturbed and wind and weather conditions happen, a source of heat must affect the temperature of the air mass and increase its water vapor content.

The sun and the weather.

The sun is the earth's great source of energy. Not only does the weather but also all life and all life-activity upon the earth depend upon the energy from the sun. The heat from the sun is transferred to the earth by means of radiant waves.

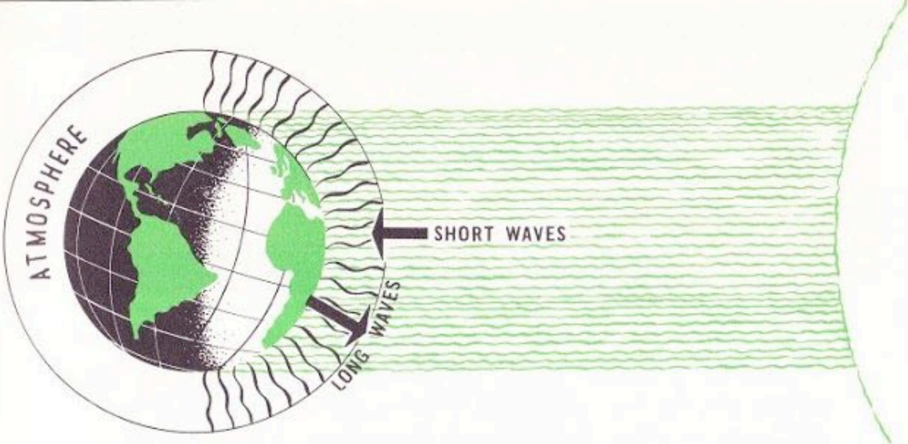
The methods of heat transfer.

There are three principal ways in which heat is transferred from one place to another. These are called *conduction, convection,* and *radiation*. Conduction is the transfer of heat between objects whose surfaces are in contact one with the other. Convection is the transfer of heat in liquids or gases by means of currents within the liquids or gases. Radiation is the transfer of heat by means of radiant waves.

Radiation.

The heat energy of the sun reaches the earth through radiation. This method transfers heat energy without changing the temperature of anything between the source of energy and the object heated. Heat energy escapes a generating source in the form of waves. These radiant waves (or rays) are themselves a form of energy. When radiant energy from one object reaches another object it changes again into heat energy.

Scientists classify radiant waves according to their length. Radiant waves of different lengths are assumed to form a band, or spectrum. At one end of this band are the shortest waves. At the other end the longest waves. Waves sent out by the sun include the ultraviolet rays, visible light rays, and infrared waves. Ultraviolet rays are invisible rays that lie beyond the violet rays toward the short-wave end of the spectrum. Infrared rays are invisible rays that lie beyond the red rays toward the long-wave end of the spectrum. The visible light rays lie between the ultra violet and the infrared rays. The waves of any of these



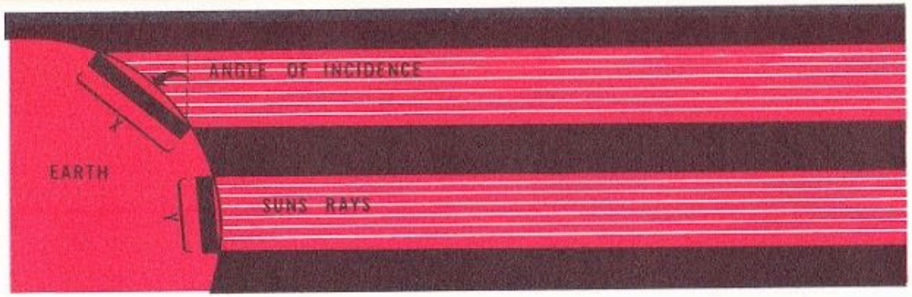
Radiation

groups are not of identical length. For example, there are short infrared waves and long infrared waves depending upon the distance of the wave from the visible red of the spectrum.

Radiant energy is never destroyed although only about 43% of the sun's radiation toward the earth ever reaches its destination. Radiant waves may be absorbed and reflected by clouds in the atmosphere; they may be scattered and reflected by dust in the atmosphere; they may be transmitted through the atmosphere; they may be absorbed by the earth and converted into heat and long-wave infrared rays. During the processes by which water from the earth's surface evaporates into the atmosphere, much heat (radiant energy) is absorbed. It takes 590 calories to change one gram of water into water vapor. And although it causes no increase in the temperature of the water vapor which results, no heat is lost. When the water vapor later condenses, heat is released and does affect the temperature of the surrounding air. This is a point to be remembered, since the heat thus released helps generate thunderstorms and the winds and violent air currents which accompany them.

Insolation.

The rate at which the earth's surface is heated is called *insolation*. Changes occur in insolation as changes occur in the angle (the angle of incidence) that the sun's rays make with the horizon, changes in the distance of the earth from the sun at any given time, and changes in the amount of radiation absorbed by the atmosphere. On clear days more radiation reaches the earth's surface than on cloudy days. Very dense cloud formations may reflect as much as three-fourths of the radiant energy from the sun.

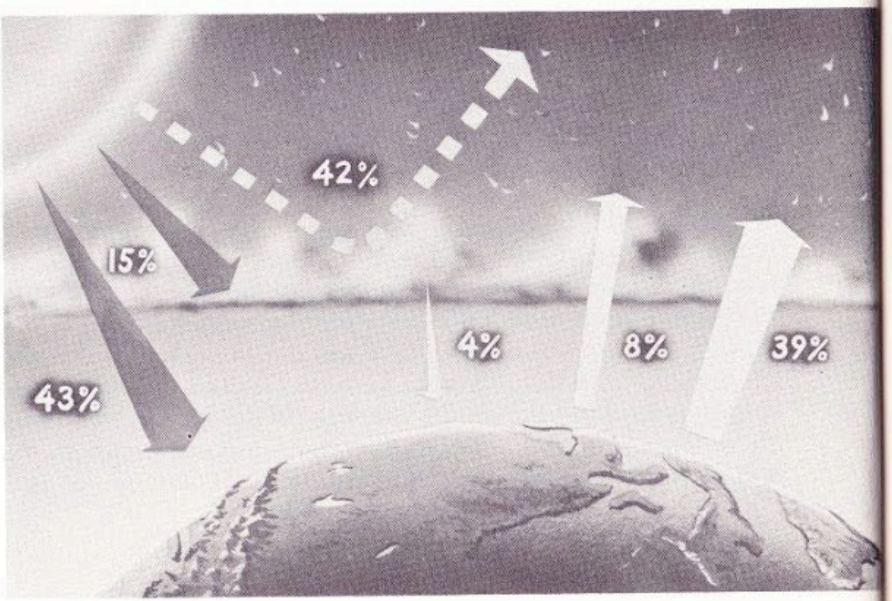


Angles of Incidence

Insolation is greater at the equator than elsewhere on the earth's surface because, at the equator, the angle of incidence is greater. (The sun's rays are more nearly perpendicular.) Consequently, more radiant waves per equal area (hence, more heat) reach the equatorial zone than reach the temperate zones, and more reach the temperate zones that reach the polar zones. (See illustration above.)

In January the earth is about 3,000,000 miles nearer the sun than it is in July. If the axis of the earth were not tilted in relation to its orbit (23.5°), January in the Northern Hemisphere would be warmer than July. The greater angle of incidence in July over January accounts for summer in the Northern Hemisphere. Seasons, of course are reversed for the Southern Hemisphere. During the summer season there, the earth is comparatively nearer the sun and the summers of the Southern Hemisphere are comparatively warmer than those of the Northern Hemisphere.

The Heat Balance



The heat balance.

Were there not a balance of heat between the earth, its atmosphere and space, the earth—bombarded continuously by radiant waves—would become increasingly warmer. This does not happen because the radiant energy received by the earth is in turn radiated from the earth into space or transferred by another means into the atmosphere.

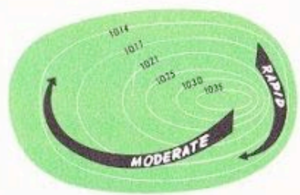
Students of meteorology have estimated that of all the solar radiation toward the earth: 42% is reflected into space by clouds and atmospheric dust and 15% is absorbed directly into the atmosphere; 43% reaches the earth; 39% is subsequently absorbed by the atmosphere after it reaches the earth's surface; 4% is again returned from the atmosphere to the earth by means of convection; 8% is radiated by the earth and transmitted through the atmosphere directly into space. The processes which tend to maintain the heat balance are chiefly responsible for weather changes.

The wind.

You have learned that insolation (the rate of heating of the earth's surface) is greater in the equatorial zone than it is within the temperate and polar zones. For this reason, the temperature of air in contact with the earth's surface within the equatorial zone rises more rapidly than does the temperature of air in contact with the earth's surface within temperate and polar zones. If the earth did not rotate, the result would establish a gigantic convection. The increase of surface air temperature would cause an increase of the air volume and the air pressure (see page 39); the upper air would move from the equator toward the poles; surface air would move from the poles toward the equator. However, the earth does rotate and irregularities characterize its surface. Consequently, the system of the winds is somewhat complex.

Air movements on a Static and Rotating Sphere

Isobars on a weather map indicate degrees of pressure within a high.



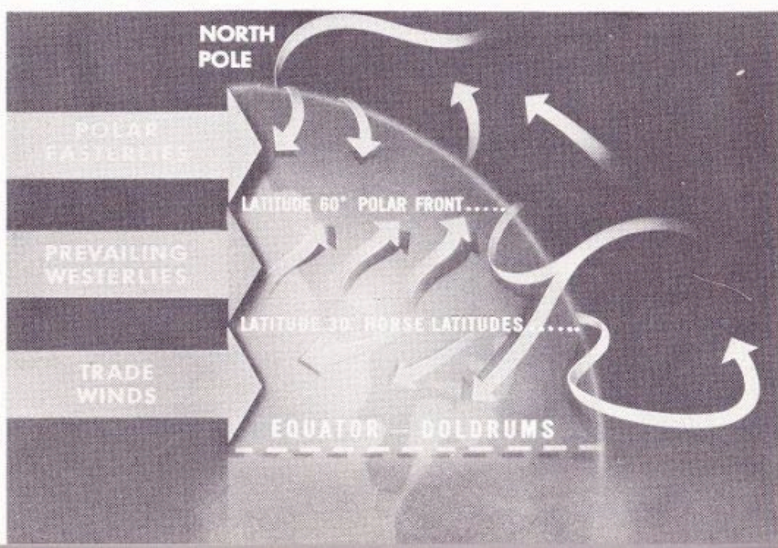
Representation of flow of air around a high.

The pressure gradient

As a result of the earth's rotation, the nature of air currents generated within the equatorial zone is modified by a factor called the *coriolis* force. In the Northern Hemisphere this force tends to deflect the wind to the right of its path. Consequently, as the heated air above the equatorial zone rises and moves northward, it tends to change its direction toward the east. By the time it reaches Lat. 30°N. it is blowing directly eastward and causes an accumulation of air and a high pressure belt at this latitude.

As the air pressure builds up within this belt, some of the air is forced downward toward the earth's surface. A portion of this flows back

Wind systems



toward the equator along the surface; another portion flows toward the poles along the surface.

Meanwhile, some of the air aloft continues to flow toward the poles, becomes cooled, settles to the surface and begins a return trip to the equator. The warmer surface air moving up from latitude 30° overruns this colder air and, continuing northward, produces a high pressure condition in the polar zones. At irregular intervals when the pressure becomes sufficient, massive air waves break out of the polar zones. These waves moving toward the equator cause the changeable weather conditions which are characteristic of the middle latitudes.

The pressure gradient and its effects upon the wind.

The irregular distribution of oceans and continents, seasonal changes, and daily temperature variations, are among the different influences which cause the atmosphere to assume the nature of a constantly changing landscape made up of invisible mountains and valleys. The high-pressure areas of the atmosphere are the mountains; the low-pressure areas, the valleys. The wind flows from these high pressure mountains into the low pressure valleys, just as great streams of water might flow from an actual mountain into a valley below.

The slope of the high pressure mountain is called the pressure gradient. On weather maps, its degree of steepness is shown by lines, similar to contour lines (see page 44), called *isobars.*[1] Isobars are drawn through points of equal sea-level atmospheric pressure.[2]

The effects of gravity and friction upon the wind.

Still other factors which affect the circulation of the air are gravity, friction, and centrifugal force. Gravity tends to pull the air downward, and produce a graduated, air-density distribution, with the greatest air-density near the earth's surface. Friction tends to retard air movement; it is effective to an altitude of 1500 to 2000 feet above the ground.

Centrifugal force acts on air moving in a curved path so as to decrease its speed within a low pressure area and increase it within a high pressure area. In the Northern Hemisphere the air flows clockwise

[1] Weather maps express atmospheric pressure in terms of millibars. A millibar is a unit of pressure equal to a force of 1000 dynes per square centimeter. A dyne is a force which applied to a mass of one gram for one second will give it a velocity of one centimeter. Standard sea-level atmospheric pressure is 1013 millibars. Atmospheric pressure may also be expressed in lbs./sq. in. or inches of mercury (Hg.).

[2] The actual atmospheric pressure of a reporting station converted to that which would prevail were the station located at sea level.

around a high pressure area (an anticyclone) and counter-clockwise around a low pressure area (a cyclone).

It should be noted that at an altitude where surface friction ceases to affect wind movement, the wind always blows parallel to the isobars. At this level, called the *gradient level,* the pressure gradient force balances the coriolus force. The wind at this level is called the *gradient wind.* Its speed is always inversely proportional to the distance between the isobars. This means that when the isobars are far apart, the wind is weak; when they are close together, the wind is strong. Pilots of long distance flights always try to take advantage of favorable winds and plan and navigate their flights accordingly.

Local air movements.

The general circulation of the air is complicated by the irregular distribution of land and water areas. Different types of surfaces differ in the rate at which they transfer heat to the atmosphere. Seasonal changes and daily variations in temperature also affect this rate of transfer. In some regions, local low pressure areas form over hot land surfaces in summer and over the warmer water surfaces in winter. Along shore lines convection currents are formed which during the day cause the wind to blow from water over the land and during the night to flow from the land over the water.

Local air circulation of limited scope is caused by the variations in the earth's surface. Some surfaces such as sand, rocks, and barren land give off a great amount of heat. Others, such as meadows, cultivated fields, and water, tend to retain heat. Rising air currents are encountered by an aircraft in flight over the one type of surface, descending air currents are encountered over the other.

Moving air flowing around obstructions tends to break into eddies. On the leeward (opposite the windward) side of mountains there are descending wind currents. Such local conditions cause turbulent air. A pilot flying into the wind toward mountainous terrain will place enough distance between his aircraft and the mountain top to avoid dangerous, descending air currents. Light plane pilots sometimes approach mountains at a 45° angle so they can turn back in a short period of time if turbulence is encountered.

The jet stream.

A jet stream is a comparatively narrow current of air which moves around either the north or south hemispheres of the earth at speeds

from 100 to 250 miles per hour. It moves from west to east at an altitude of approximately 30,000 feet.

Air speeds increase toward the core of the stream. An aircraft climbing or descending through a jet stream may encounter differences in wind speeds of 30 miles an hour per 1000 feet of altitude change. A difference in wind speed of 100 miles per hour between the outer edge and the core of the stream is not unusual. Also, differences in wind speeds up to 100 miles per hour between regions of maximum and minimum wind speed along the core of the jet stream may be expected.

The jet stream shifts position frequently and actually migrates with the seasons. Sometimes two streams flow across the United States, the one along the northern border and the other well toward the south. The cruising range of an aircraft flying downwind within a jet stream is greatly increased. However, flying against a jet stream limits the cruising range and such flight operation should be avoided. Consequently, pilots anticipating high altitude or long range flights attempt to discover the location of the jet stream.

Humidity.

Water vapor enters the air when the surface water absorbs enough solar radiation in the form of infrared rays (see page 41) to change its state from liquid to gaseous. Under average circumstances the atmosphere contains 12 parts of water vapor to 1,000 parts of air.

Water may be found in the atmosphere in any one of its three forms: solid, liquid, or gaseous. However, it is in the form of gas (vapor) that water is first mixed with air. The other forms result when water vapor condenses.

The term, *dry air,* characterizes air that contains no water vapor. The term, *humid air,* characterizes air that contains water vapor. When a parcel of air can contain no more water vapor, it is said to be saturated. The amount of water vapor which the air can contain depends upon the air temperature. The ratio of the amount of water vapor which a sample of air holds to the amount it can hold when saturated is called relative humidity.

Condensation.

When the relative humidity of a parcel of air is 100%, it becomes saturated. Should the temperature of such a body of air be reduced, some of the water vapor it contains would become liquid. Moreover, *the heat used to change its state from liquid to gas, as a result of such condensation, would be released into the atmosphere.*

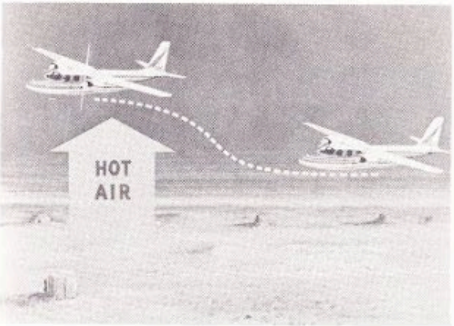
Before condensation can take place, the atmosphere must contain condensation nuclei. Large quantities of these are generally present in the form of tiny particles of dust and minute products of evaporation. The products of condensation include clouds, rain, drizzle, hail, dew, freezing rain, freezing drizzle, snow, frost, and sleet. Before any form of precipitation can occur, even after the air reaches its saturation point, clouds must form and water droplets must be super-cooled (reach a temperature below freezing).

Temperature and altitude.

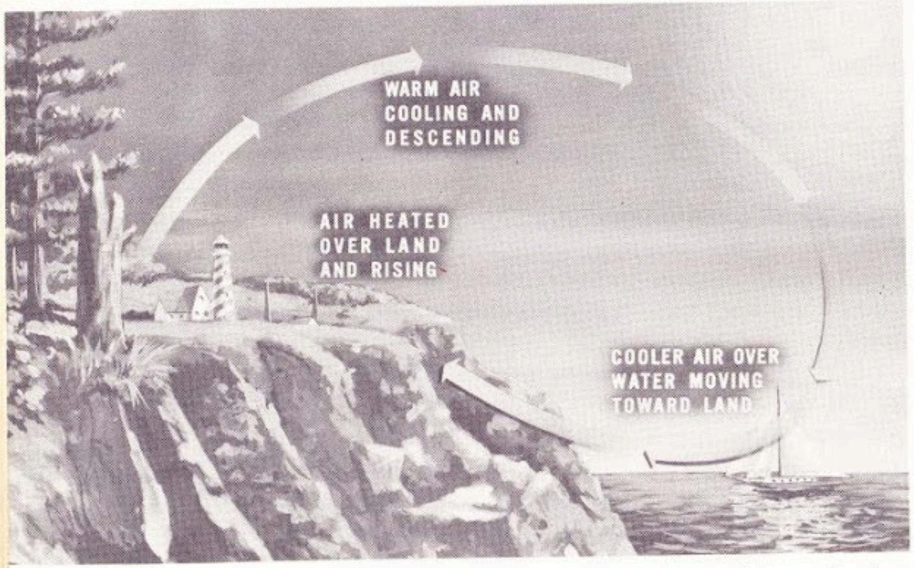
Both the temperature and the pressure of the air decrease with an increase of altitude. Perfectly dry air decreases in temperature at the rate of about 5½ °F. per each 1,000 feet of elevation (dry adiabatic lapse rate); under average humidity conditions air temperature decreases at about 3½ °F. per each 1,000 feet of elevation (normal adiabatic lapse rate). The rate of temperature decrease with altitude for moist air depends upon its relative humidity.

As a parcel of air ascends and gains altitude it experiences lowering pressures. Consequently, it expands. When a gas expands, work is done and heat energy is converted into mechanical energy. As a parcel of air descends, it is subject to increasing pressure, the process of energy change is reversed, and the temperature of the air is increased. When no heat is added to such a parcel of air, any expansion or compression which brings about a temperature change is called an *adiabatic process.* If the expansion or compression of an air parcel results from heat added to or taken from it, the process is *isothermal.*

Both the isothermal process and the adiabatic process are important factors in weather changes. It appears that the isothermal process initiates both the air mass movements and the local convection currents. These air movements and currents cause the lifting of air parcels. Condensation results when ascending air is affected by the adiabatic process. Release of the latent heat of condensation adds heat to the air; consequently the isothermal process again takes place. The violent air currents which characterize thunderstorms are caused in part by the expansion of the air which takes place when additional heat energy becomes available.



CHAPTER SEVEN

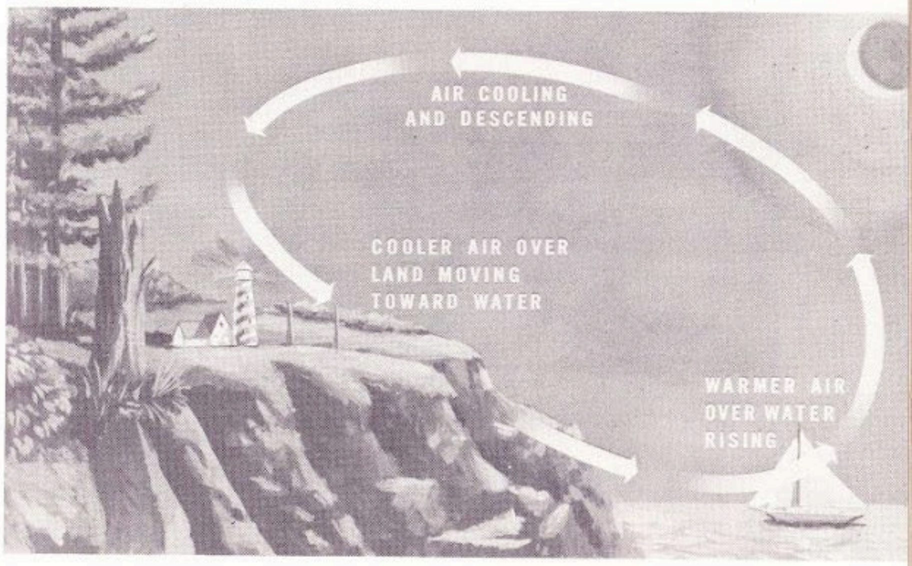


Local air circulation, daytime

VII. AIR MASSES, FRONTS AND WEATHER HAZARDS

Although clouds and fog may form because of conditions and procedures within an air mass, general weather changes are the result of the meeting of air masses having different characteristics. Air mass characteristics parallel those of the area in which the air mass originates. A polar air mass (P) is cold; a tropical air mass (T) is hot; a maritime air mass (m) is humid; a continental air mass (c) is dry.

As an air mass moves away from its source of origin its original characteristics are changed because of the nature of the earth's surface over which it passes. It may become warmer or colder; absorb moisture or lose moisture; be lifted by mountains or subside into valleys. However, an air mass is not likely to lose all of its original characteristics.



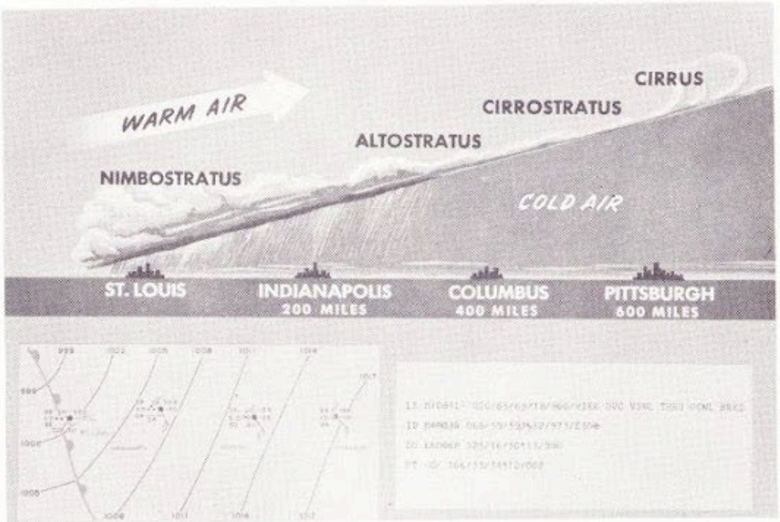
Local air circulation, at night

Temperature classification of air masses.

The temperature classification of an air mass is based upon its temperature in relation to the surface over which it passes. As an air mass moves from one surface to another it could change from a cold air mass (k) to a warm air mass (w), or from a warm air mass to a cold air mass. On weather maps an air mass is identified by letter symbols. An air mass originating in the polar zone and moving toward the south over a comparatively warm surface will be identified on a weather map by the symbol cPk. An air mass originating over the Gulf of Mexico and moving toward the north over a comparatively cold surface will be identified by the symbol mTw.

Characteristics of air masses.

The characteristics of an air mass depend upon the seasons, its distance from its source of origin and the position of the observer in relation to the frontal zone of the air mass (front). In general, a cold air mass is characterized by cumulus and cumulonimbus clouds (see illustration, page 53), by local thunderstorms, showers, hail, sleet, or



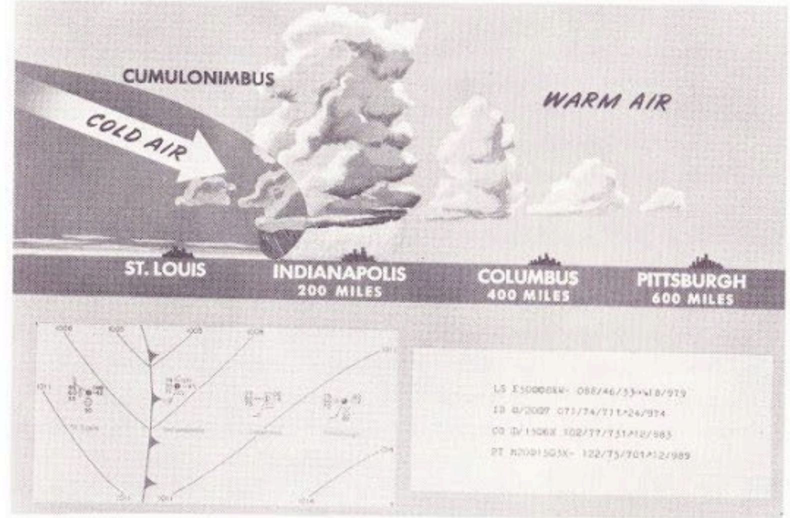
The Warm Front

snow flurries. Pronounced turbulence exists in its lower levels; yet, except during precipitation, the cloud ceiling is usually unlimited and visibility conditions are good. On the other hand, a warm air mass is characterized by haze, fog, stratus clouds, and drizzle. Warm air masses have little or no turbulence; yet, visibility conditions are poor and cloud ceilings generally low.

The general movement of the atmosphere across continental United States is toward the east. Air masses originating in the tropical and equatorial areas move toward the northeast. Those originating in the Arctic and Polar areas move toward the southeast. Cold air masses move more rapidly than warm air masses. The speed of an air mass may average from 500 to 700 miles in a day, depending upon its nature and the season of the year.

Fronts.

The boundaries set up between one another by air masses of different characteristics are called frontal zones or *fronts*. This boundary or front moves along the earth's surface as one air mass tends to displace another. If a cold air mass tends to replace a warmer air mass, the boundary is called a *cold front*; if a warm air mass tends to replace



The Cold Front

a cold air mass the boundary is called a *warm front*. When there is a marked temperature and humidity difference between the two air masses, weather changes along a front are pronounced.

The cold front.

Cold air is denser and heavier than warm air. Because of this fact, the warm air lying ahead of a moving cold front is lifted, and its temperature is lowered. The result is a belt of frontal activity (a squall line) 50 to 100 miles wide which may extend for hundreds of miles in length. In the United States such fronts extend from southwest to northeast.

The cold front has a steeply curved slope. Its progress is more rapid than a warm front. If its movement is comparatively slow, nimbostratus clouds are formed at the front. If its movement is comparatively rapid, cumulonimbus clouds will form and heavy precipitation and turbulent winds will occur.

A cold front causes a complete change of weather within the space of a few hours. After a cold front passes, the wind direction will change, the weather will clear, and the air will become cooler and drier.

The warm front.

A moving warm front overrides the cold air ahead of it, forming a wedge like segment of cold air directly below its slope. This slope is comparatively gradual. It rises about 1,000 feet for every 20 miles. It may extend for several hundred miles. As the warm air moves up the slope and its temperature falls, condensation occurs. Fog and drizzle first occur; low nimbostratus clouds then form, and the drizzle turns into rain; at increasing heights along the slope stratus, altostratus, and cirrostratus clouds form. Wisps of cirrus clouds may lie on a warm front slope at an altitude of 20,000 feet and 400 or more miles ahead of the intersection of the frontal slope with the earth's surface. Unlike the cold front, the warm front signals the weather changes it is to bring. Just as a change in wind direction takes place after a cold front passes, so does a wind shift take place after a warm front passes.

The occluded front.

The development of occluded fronts is associated with the development of low pressure areas. Under certain conditions there is a tendency for a wave motion to occur along a front. This wave is not vertical like an ocean wave, but is horizontal. After the frontal "bend" starts it takes three or four days for the process to be completed. A second stage occurs as the cold air begins to surround the warm air. The warm air, rapidly lifted, cools and severe precipitation occurs. The final stage is reached when the warm air is completely surrounded. The air pressure then becomes less at the wave than at other points within the surrounding areas, the frontal surfaces tend to whirl together, and a "low" has been created.

As the occluded front approaches, one may observe warm front weather characteristics. Lowering cloud ceilings, lowering visibility, and increasing precipitation takes place in the order stated. Following the warm front weather, cold front type weather occurs—squalls, thunderstorms, and turbulence.

Clouds.

Clouds are sometimes called the signposts of the weather. There are two general types under which all clouds can be classified. These types are cumulus and stratus. (See illustration, pages 52 & 53.)

Cumulus clouds appear to be piled one on top of another. They are formed by vertical currents. Stratus clouds are spread out in layers. Clouds near the earth's surface are designated as either cumulus or

THE AVIATION WEATHER REPORT

STATION IDENTIFICATION ①
TYPE OF REPORT ②
CEILING ③
SKY CONDITION ④
VISIBILITY ⑤
WEATHER ⑥
OBSTRUCTION TO VISION ⑥
SEA-LEVEL PRESSURE ⑦
TEMPERATURE ⑧
DEWPOINT ⑨
WIND ⑩
ALTIMETER SETTING ⑪
REMARKS ⑫

PIT S7 M3V ⊕7⊕ 11/2VL-FK 146 /66 /65 →3 /997 /CIG 2V4 VSBY 1V2

The weather sequence report

stratus unless they are producing precipitation. When they are producing precipitation, the term nimbo is added either as a prefix (nimbostratus) or as a suffix(cumulonimbus). The term alto is added to cumulus or stratus to identify such types when they lie between 5,000 and 20,000 feet. The term *fracto* is prefixed to the names of the general types when clouds appear broken. Clouds between 20,000 feet and 50,000 feet are composed of ice crystals, have a characteristic curly appearance, and are called cirrus clouds. The term *cirro* prefixed to cumulus or stratus identifies the different types of cirrus clouds.

It is quite easy to remember the names of the clouds. Simply learn the names of the two basic types: cumulus and stratus. Then remember the meaning of the terms combined with these names: *nimbus* means rain; *alto* means high; *fracto* means broken; *cirrus* means curly.

The weather elements.

In order to gather weather information and to report this to forecasting centers so that future weather can be predicted, ten weather characteristics are measured. These conditions are (1) sky cover, (2) cloud ceiling, (3) visibility, (4) state of the weather, (5) pressure, (6) temperature, (7) dewpoint (humidity), (8) wind direction, (9) wind velocity, and (10) precipitation. The variations of three of these elements can be measured only by the eye (visually); variations of the others are measured by instruments.

Symbols are used to report weather conditions. Weather maps or charts use one set of symbols. Weather reports use another. The chart symbols which disclose weather information are clustered around the reporting station. Such a cluster of symbols is called the station report. The illustration below (see page 57) shows the conventional position of each symbol in a station report. You will note that the number of feathers and half feathers at one end of the arrow in this illustration indicates the strength of the wind. The compass direction from which the wind is blowing is indicated by the position of the arrow. You will note that the circular symbol at the other end of the wind arrow indicates the amount of sky cover. To report "state-of-the-weather" under differing circumstances requires over one hundred symbols. Six of these are of more importance than the others, either because they are the basis of other symbols or because they reveal hazardous weather conditions. (See illustration, page 57.)

Although weather maps are of primary importance as tools for the meteorologist, they are also important to the pilot. From them the latter can obtain information about high and low pressure areas and the position and nature of fronts and squall lines at the time of observation. From the map he can discover the general weather conditions along and near the route he plans to fly. However, it is from weather sequence* reports and forecasts (area, terminal, or winds aloft) that the pilot obtains specific weather information.

Weather maps are drawn from observations made at six-hour intervals beginning each day at 0130 Eastern Standard Time. Aviation weather reports are made at hourly intervals, at 30 minutes past the hour. Weather reports and forecasts are transmitted by teletype. Hundreds of these are transmitted each hour. They must be both complete and concise. In order to assure these qualities and to expedite their transmission, symbols and abbreviations are used to convey weather information.

A group of teletype weather reports will be prefaced by abbreviations indicating the nature and time of the reports, for example FCST 05E-17E (Forecast 5 A.M. to 5 P.M. Eastern Standard Time). Each report of the group will be introduced by the name (abbreviated) of the reporting station. If a significant change in the weather has occurred since the previous report was made, the letter S followed by a number will be the second item of the report. The S indicates a "special report"; the number is the number of the special reports made during the reporting day. The other items correspond in the order of their arrangement to the order in which the weather elements are generally listed. (See above, page 55.) In addition, the report contains the proper altimeter setting and pertinent remarks. The illustration above (see page 55) provides a key to the interpretation of aviation weather reports.

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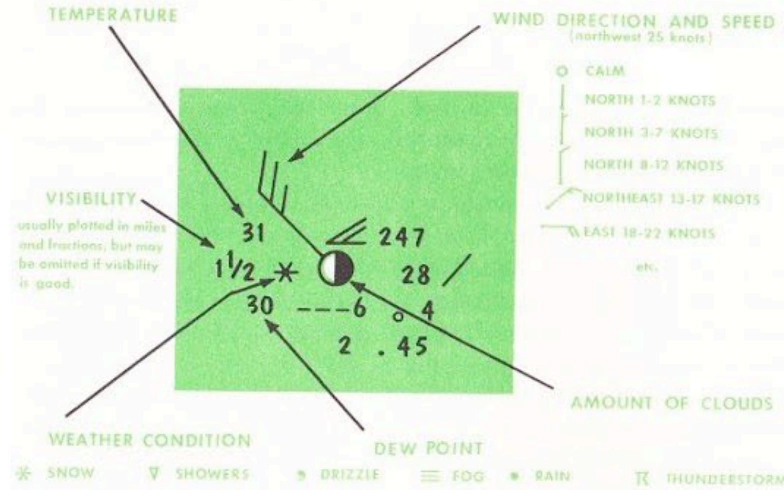
* Each related to the preceding.



The Station report

Area and terminal forecasts make use of some of the symbols used in weather reports. They also use certain other symbols. One of the charts displayed at weather stations tells pilots how to interpret the symbols of a forecast (see illustration above).

As a student of general aviation you should learn the few basic symbols used in weather reporting. To do this will help you learn specific symbols readily, should you at some later time wish to become skilled in map reading and weather report interpretation. For the present it is important only that you understand the purpose and general method of weather reporting.

The weather hazards to aviation.

A principal weather hazard to aircraft in flight is the thunderstorm. Turbulence, high winds, heavy rain, lightning, and sometimes hail characterize thunderstorms. A thunderstorm has three stages: (1) the cumulus stage, (2) the mature stage, and (3) the dissipating stage.

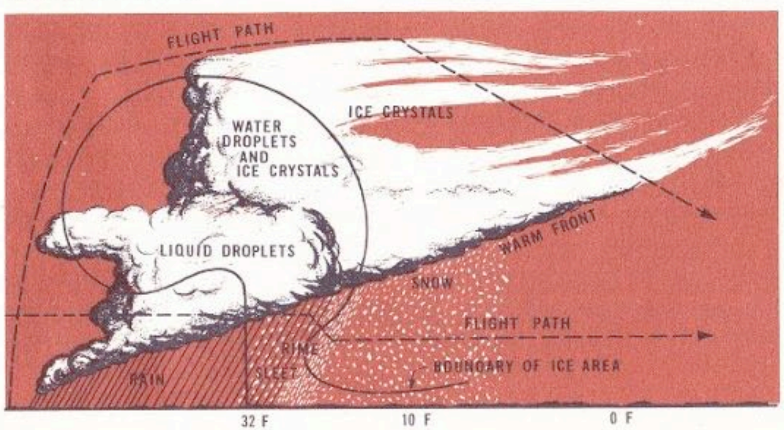
The thunderstorm develops during the cumulus stage. This stage is characterized by updrafts. They may extend from the surface to an altitude of 25,000 feet, and they may have vertical speeds up to 30 miles per hour. When rain begins to fall, the thunderstorm has reached the mature stage. During this stage there are both updrafts and downdrafts. Updrafts are sometimes strong enough to carry liquid water to a height where hail will form. Great turbulence takes place within the thunderstorm. As the thunderstorm nears the dissipating stage the downdraft area increases in size. After this stage is reached the thunderstorm contains only downdrafts, the rainfall gradually decreases, and the thunderstorm activity stops.

Thunderstorms may be single or multi-cell. A single cell thunderstorm is rare. Its life cycle is completed in about one hour and fifteen minutes. Multi-cell thunderstorms may contain cells in various stages of development and may remain active over a period of hours. Under no circumstance should pilots of small aircraft attempt to fly through thunderstorms.

The formation of ice on aircraft may become a hazard to safe flight. This is the case when an aircraft is not equipped with means for disposing of ice formation on the propeller and the wings. Before ice can form on an aircraft, the aircraft must be flying through moisture that is visible, such as clouds, rain, drizzle, or wet snow. (Carburetor icing, you remember, can take place when there is only *water vapor* present in the air.) Icing generally occurs when the temperature is between 32°F. and 20°F. However, it may occur when the temperature is lower than 20°F. Consequently, a pilot who wishes to avoid ice will stay clear of clouds or precipitation areas when the temperature is below freezing.

Low visibility conditions may also cause hazardous flying conditions. These conditions result from haze, smoke, fog, snow, low clouds, or other obstructions to a pilot's vision. Ceiling and visibility are two weather elements that every pilot carefully considers before undertaking a flight. These two factors help determine whether the flight can be made VFR or whether an IFR flight clearance must be obtained from Air Traffic Control (see *Airports, Airways, and Electronics,* page 46).

The Thunderstorm



SUMMARY

Navigation was first practiced by those who operated ships at sea. After the airplane was invented and aircraft came into practical use, the principles of navigation were borrowed from the seafarer by the aircraft pilot. For, the problems of keeping an aircraft on course and those of keeping ships on course are solved by the use of similar methods. Navigation is both a science and an art. It is a science in that it employs well-established principles and recognizes proven procedures. It is an art in that it requires from the one who practices it an adaptability to an ever changing situation. This is because the navigator must always take into account such variable factors as wind and weather.

Of first importance to the flight navigator is the aeronautical chart. His basic navigation instruments are his watch, an airspeed indicator, a magnetic compass, and an altimeter. By means of the meridians of longitude and the parallels of latitude, the coordinates of his chart, he locates his position. By means of the proper meridian and a protractor, he finds the course which he must make good to reach his destination. By use of his watch and check-points he can check his ground speed and estimate his arrival time. His compass indicates a heading; his airspeed indicator gives the approximate speed of his craft through the air; and his altimeter shows the approximate height of his craft above the ground. Whatever the type of navigation he practices, the pilot finds the basic navigation instruments indispensable.

The types of navigation are piloting, dead reckoning, radio flight, and celestial navigation. Charts are made use of in every type of navigation. Piloting and dead reckoning are used to navigate short-distance flights. It is the general practice for a pilot to use a combination of navigation types. Radio flight requires complex equipment; but it makes the task of the navigator simple.

The magnetic compass does not indicate a true course. The attraction of the magnetic pole causes the compass needle to vary, depending upon the region of an aircraft's flight. Some of the metals used in an aircraft's construction and the electrical instruments with which it is equipped may cause deviations of the compass needle regardless of the region of an aircraft's flight. These facts must be considered in calculating a compass course.

The direction and speed of the wind are factors which a pilot must consider when he needs to find the compass heading which will enable him to make good the desired true course. Wind and weather create many operating problems that pilots and navigators encounter.

A principal source of energy on earth is the sun. The method by which it is transmitted to the earth is called radiation. After reaching the earth, radiant energy changes to heat energy. Heat energy raises the temperature of the air, increasing its pressure and its volume, and establishes convection currents. Because of the difference in insolation between the tropic zone and the temperate and polar zones, general air movements are initiated. A force created by the rotation of the earth, called the coriolus force, deflects these movements and helps cause the winds.

Air masses, their characteristics, and the weather activity which takes place when different air masses come into contact one with another are important in the operation of aircraft. The characteristics of an air mass are determined by the nature of the earth's surface over which it originates and over which it passes. An air mass is hot or cold, dry or moist, depending upon whether or not such surfaces are hot or cold, dry or moist. Frontal activity occurs when moist warm air is lifted by colder air. Air cooling adiabatically loses its water vapor content through condensation. Condensation releases the heat employed to evaporate the water originally. The release of heat contributes to atmospheric turbulence and to further atmospheric changes.

The types of fronts can be identified by the clouds that precede them. Pilots should learn the meaning of these signposts of the weather. In this way many hazards to safe navigation such as icing and low visibility conditions and thunderstorms may be avoided. The practice of navigation requires knowledge and skill on the part of pilot and navigator. It also requires the exercise of good judgment. This is particularly true in the case of the light plane pilot. His flight must be planned carefully. A most important part of that planning requires that the pilot learn about the wind and weather conditions likely to prevail at the time of his flight, and that he navigate his aircraft with this information in mind.

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