STUDENTS' MANUAL

Navigation for Bombardiers

ARMY AIR FORCES TRAINING COMMAND

RESTRICTED

STUDENTS' MANUAL

Navigation for Bombardiers

Prepared by the

ARMY AIR FORCES TRAINING COMMAND

Visual Training Department, in Collaboration with the

ARMY AIR FORCES INSTRUCTORS' SCHOOL (BOMBARDIER)

M.A.A.F., Midland, Texas

TO BE USED AS A SUPPLEMENT TO CURRENT AAF TRAINING COMMAND MEMORANDUM COVERING BOMBARDIER TRAINING

ARMY AIR FORCES TRAINING COMMAND

Foreword

The purpose of a bombing mission is to find the target, deliver the bombs, and get home. Successful execution of the mission depends in no small part on accurate navigation. Guiding the airplane, of course, is the navigator's responsibility. But there are many sound reasons why you, the bombardier, must know a good deal about navigation.

In the first place, two heads are better than one. You can assist the navigator by checking your data against his. More important is the fact that you must be ready to take over the navigator's duties, if he should become disabled. Your life, and the lives of your comrades, may depend on your ability to guide the airplane back to a safe landing in friendly territory.

Constant and careful observation of the ground will sharpen your sight and make it easier for you to pick out the exact target within the general target area. Make no mistake about it: *practice in navigation will make you a better bombardier.*

B K Yount

Lieutenant General, U.S.A.
Commanding

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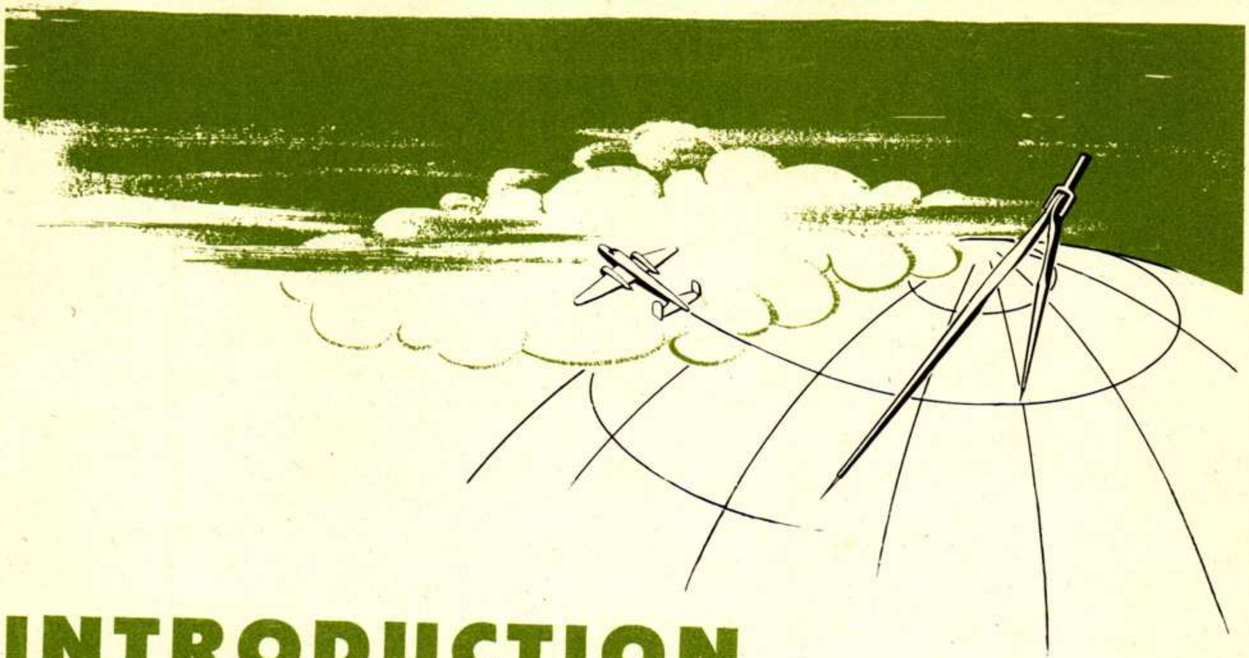


INTRODUCTION

Aerial navigation is the art of guiding an airplane from one point on the earth's surface to another. To navigate successfully, you need to know at all times where you are, where you came from, and where you are going. The problems of navigation are problems of **direction** and **distance**. Your job is to guide an airplane a given distance in a given direction.

When you travel on the surface of the earth, you find your directions and distances by using information from maps, landmarks, road signs, and oral instructions. In the air, you use the same **principles** of navigation as on the ground, but you get your **information** from other sources. There are no highway markers in the air and there are no obliging natives to direct you. You have to determine your directions and distances yourself, using what facts you may have.

There are four **methods of aerial navigation**: Pilotage, dead reckoning, radio navigation, and celestial navigation. They are alike in purpose and in the basic principle of finding direction and distance. They differ in the kind of facts each uses to solve the problem.

Pilotage is the oldest form of navigation. It is the method of guiding an airplane by simply looking at the ground over which you are flying. When you navigate by pilotage, you determine directions and distances by looking at objects on the ground and determining the position of your airplane in relation to them. These reference points may be landmarks you know or ones you can recognize from a map.

Dead reckoning enables you to determine direction and distance when you cannot see the ground, or when you are flying over water or any area where there are no landmarks. In navigating by dead reckoning you use information supplied by your instruments together with knowledge of the wind. By a constant series of computations, using airspeed, wind drift, and compass readings, you can forecast an estimated time of arrival at your destination.

Radio navigation is the method of finding direction and distance by information received from radio aids. **Celestial navigation** uses the heavenly bodies as guideposts. You will not study here these last two methods.

Pilotage and dead reckoning are the two methods of navigation you must learn and use. Since pilotage is the surest, use it whenever possible. Dead reckoning is the basis of all navigation, and you must use it when you cannot find your way by pilotage.

THE EARTH

All flights are made from one point on the earth's surface to another. When you navigate, you must locate your point of departure and destination **on the earth,** and at all times in flight locate the airplane in relation to points on the earth. Since all directions and distances in navigation are computed in relation to the earth, you must have some knowledge of the globe over which you fly.

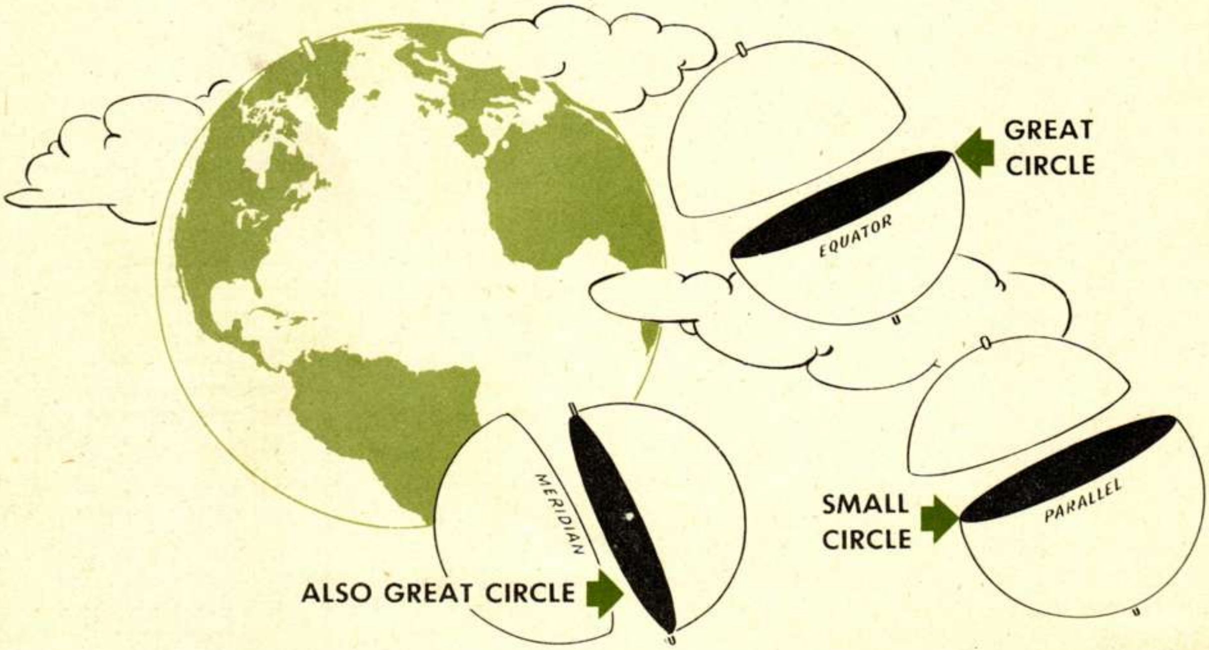
The earth is shaped very much like a ball. It is not a perfect sphere because it is slightly flattened at the poles and slightly bulged at the equator. But for all practical purposes, including navigation, it is considered to be a perfect sphere.

This sphere spins rapidly around an imaginary line within itself called its **axis**. The points on the surface of the earth at the ends of the axis are the north pole and the south pole. The equator is an imaginary line drawn around the earth halfway between the two poles. The plane of the equator is perpendicular to the axis.

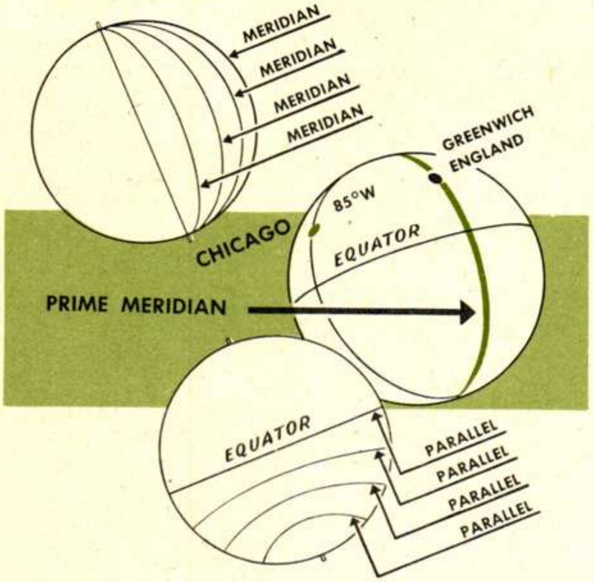
The first necessity for navigation is some method of locating points on the earth. To do this, you must have lines of reference. Any reference line drawn on the surface of a sphere must be an arc of either a **great circle** or a **small circle**.

A great circle is a circle on a sphere whose plane passes through the center of the sphere. You can draw an infinite number of great circles on any sphere. Such circles are called "great" because you cannot draw on the sphere any larger circle. If you cut a sphere in two along the line of a great circle, the two pieces are exactly equal. The important thing for you to remember is that **the shortest distance between any two points on a sphere is measured on the great circle which includes those two points.**

Any circle whose plane does not pass through the center of the sphere is called a small circle. When you cut a sphere in two in such a way that one piece is larger than the other, you have cut along a small circle.



These lines which can be drawn on the surface of a sphere can be used to set up reference points. If you draw a line from the north pole to the south pole, you have drawn half of a great circle. Such a line is called a **meridian**. You can measure distances on the earth's surface in degrees east or west from a given meridian. In order to have a fixed reference line, navigators select the meridian which passes through the town of Greenwich, England, and all measurements east or west are made from it. It is called the **prime meridian**, or **zero meridian**.



Distance east or west from the prime meridian is called **longitude**. To find the longitude of the meridian which passes through Chicago you measure the angle between the planes of the prime meridian and the meridian of Chicago. This angle is 85°, and the longitude of Chicago is 85° W. Since there are 360° in a circle, you can measure 180° east of the prime meridian and 180° west.

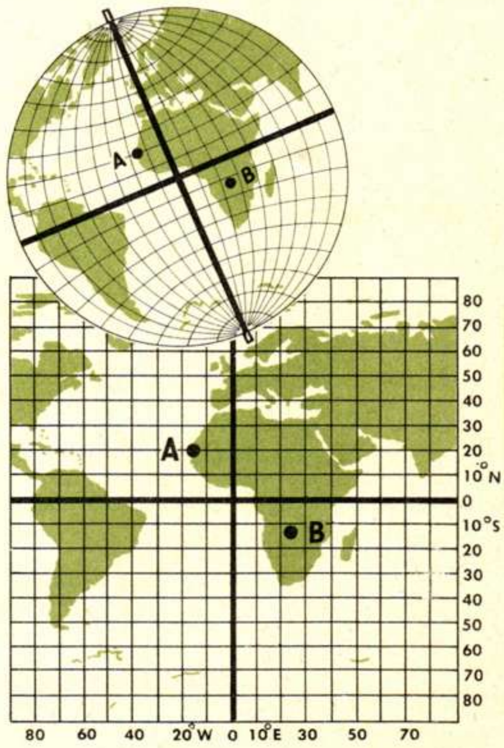
To measure distance north and south use the equator as your line of reference. Remember the equator is the only great circle whose plane is perpendicular to the axis of the earth. It is midway between the poles.

All other circles whose planes are perpendicular to the axis are small circles. They are called **parallels of latitude**. The equator is the zero parallel. You can measure the distance from the equator to a given parallel by measuring the angle between the plane of the equator and a line drawn from the center of the earth to a point on the parallel. This distance is called **latitude**. Since you can measure north only from the equator to the north pole, one-fourth of the distance around the earth, you have a maximum of 90° north latitude. Similarly, you can measure up to 90° south latitude.

When you move from the parallel of 20° N to the parallel of 50° N, you have moved north 30°. This distance of 30° north is called **difference of latitude.** If you go south from 20° N to the parallel of 10° S, you have traveled south 30° difference of latitude. Difference of latitude is the actual distance in degrees between two parallels of latitude.

Difference of longitude is the actual distance in degrees between two meridians. If you move west from the meridian of 40° W to the meridian of 70° W, you have moved west 30° difference of longitude. If you move east from the meridian of 40° W to the meridian of 24° E, you have moved east 64° difference of longitude. Similarly, the distance west from the meridian of 178° W to the meridian of 178° E (across the 180° meridian), is 4° difference of longitude.

Each degree can be divided into sixty minutes (60′), and each minute into sixty seconds (60″). A parallel of latitude can be



drawn parallel to the equator through each degree, minute, and second of the prime meridian. Thus a given parallel might be located at 20°29′N. This is called the **coordinate** of latitude of all points on this parallel.

In the same way, meridians can be drawn through the two poles and through each degree, minute, and second on the equator, and a given meridian might be located at 10°40′ W. This is the **coordinate** of longitude of all points on this meridian.

By using the **system of coordinates** you can locate any point on the earth's surface. That is, you locate the parallel of latitude and the meridian of longitude which intersect at the point. For instance, you say that the location of a given point is 20° N 10° W. You always give the coordinate of **latitude first.**

On the ordinary flat map, meridians and parallels intersect each other to form a grid. By using the coordinates, you can locate accurately any position on such a map. Thus position A is at the intersection of the parallel 10° N and the meridian 20° W. It is therefore described as 10° N 20° W.

To locate position B on the grid, first find the parallel of latitude which passes through it. Since B is south of the equator, count the parallels **down** from the equator. Since these parallels are 10° apart, and B is halfway between the second and third, the latitude of B is 25° S. Similarly, B is halfway between 0° and 10° east of the prime meridian. The longitude of B is 5° E. B is located at 25° S 5° E, the point at which the coordinates intersect.

On large scale maps, positions can be located with extreme accuracy by finding the coordinates in degrees, minutes, and seconds. Thus a given position might be located at 20°14′27″N, 10°42′13″W.

For all practical purposes of aerial navigation, location within one-half minute is sufficiently accurate. On the sectional and regional maps you use, parallels and meridians are drawn and labeled at ½° intervals.

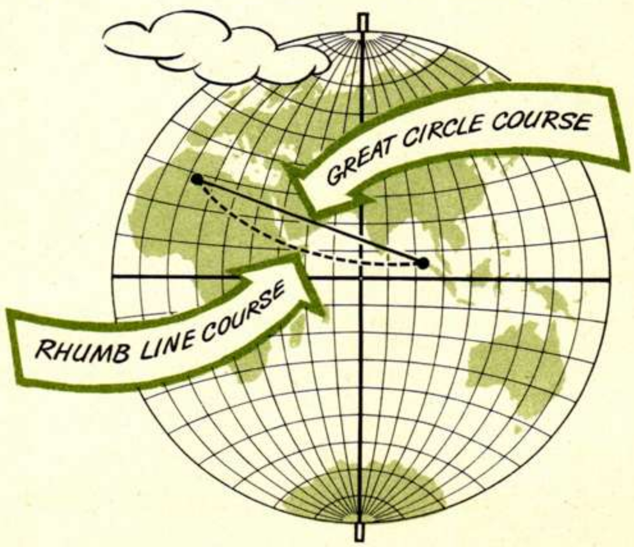
For measuring linear distances on the earth's surface, you use the **nautical mile** as your unit. A nautical mile is the actual length of an arc subtended by **one minute of latitude.** Therefore there are 60 nautical miles in one degree of latitude. Between the equator and one of the poles there are 90°, or 5,400′, of latitude. The linear distance on the earth's surface from the equator to one of the poles is therefore 5,400 nautical miles.

A nautical mile is 6,080 ft., whereas a statute mile is 5,280 ft. If a distance is given in nautical miles, you multiply it by 1.15 to convert it to statute miles. Thus 60 nautical miles $= 60 \times 1.15 = 69$ statute miles. Naturally, to convert statute miles to nautical miles, you divide the number of statute miles by 1.15.

When you fly from one point on the earth's surface to another, the only reference you can use for the direction of your flight is true north. In order to keep flying directly toward your destination, you must keep your relation to true north constant. To do this, your course must intersect all meridians at the same angle, since all meridians point due north and south.

Any line which intersects all meridians at the same angle is called a **rhumb line.** On any flight, you fly a course which is either a rhumb line or a series of rhumb lines. The shortest distance is a great circle, but you cannot fly the great circle because it does not intersect all meridians at the same angle. If you tried to do so you would have to re-orient your airplane constantly with respect to true north. Instead, you fly the rhumb line, which is longer but more certain.

On a short flight, the rhumb line course is slightly longer than the great circle course. On a very long flight, it is considerably longer. Therefore, on a long flight you fly a **series** of short rhumb lines, so as to make good a course near to the great circle.



PROJECTIONS

In order to navigate successfully, you need a map or chart of that part of the earth's surface over which you intend to fly. Since the earth is a sphere, the best map would be spherical because it would represent the earth as it actually is. But to be useful, such a sphere would have to be far too large to be carried in a bombardier's compartment.

Therefore, you need some method of representing the earth or part of the earth on a flat surface. The method of representing a spherical surface on a flat surface is called a **projection**. The representation itself is called a **map** if it covers land areas and a **chart** if it covers water areas. For your purposes, however, the words **map** and **chart** are used interchangeably.

If you took half an orange peeling and tried to spread it out flat, you know that you cannot do it without wrinkling or tearing. Similarly, the spherical surface of the earth cannot be represented on a flat piece of paper without some distortion of certain features.

The perfect projection has not been discovered, and no map has all perfect features. You must therefore use various maps made from different projections, using each map for the purpose it serves best.

Characteristics of an IDEAL MAP

An ideal map for use in navigation would have the following characteristics:

1. A great circle would be represented as a straight line. Since a great circle is the shortest distance between two points on the earth's surface, measurement of distances on a map would be simpler if the great circles were shown as straight lines.
2. A rhumb line would be represented as a straight line. An airplane flying a constant heading traces a rhumb line over the earth's surface. In measuring course, it is easier to measure along a straight line than along a curved one.
3. The ideal map would have a constant distance scale. It is much easier to use a constant distance scale than it is to use a varying scale for each section of the map.
4. Positions would be easily plotted. Since positions are located by the intersection of co-ordinates, it is easiest to plot on a map on which intersecting parallels and meridians form a perfect grid.
5. The ideal map would give a true representation of the size and shape of areas.
6. Angles on the earth's surface would be shown as the same angle on the map.

If you had a map with all these characteristics, you could use this one ideal map in all situations. But it is impossible to construct **one** map with **all** these characteristics. You cannot represent a three-dimensional sphere on a two-dimensional plane surface without some distortion resulting.

Some maps have less distortion than others. The amount of distortion depends on the method of projection used in making the map.

The same thing is true of the ideal features on a given map. Although no one map has all the ideal characteristics, each map has one or more of these ideal characteristics. Therefore, to solve your navigation problems you use several different maps made with different methods of projection, using each map for the purpose it serves best.

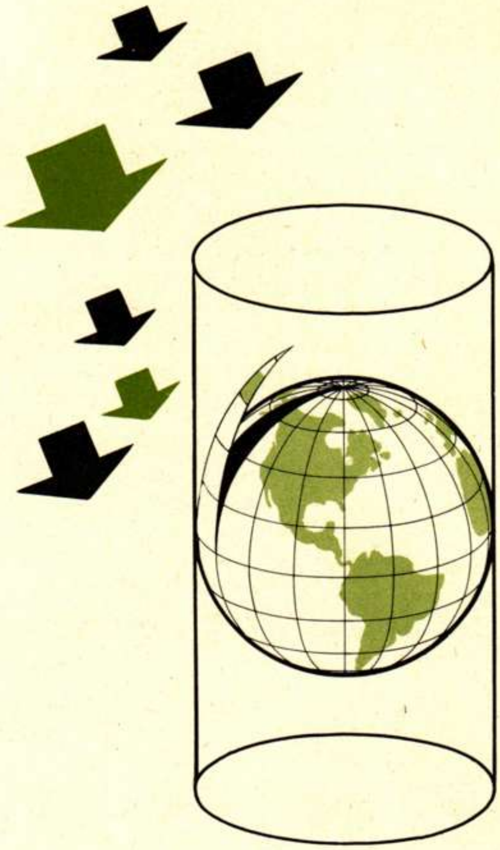
TYPES OF PROJECTIONS

There are five general kinds of projections in general use.

1. **Mercator**
2. **Lambert Conformal**
3. **Gnomonic**
4. **Polyconic**
5. **Polar Stereographic**

In most of your navigation, you will use only maps made from the first two projections: **Mercator** and **Lambert conformal.** However, for planning long flights you need to understand also the **gnomonic** projection. The polyconic projection is used principally in making maps for ground military operations, and the polar stereographic projection is used only for maps of the polar regions. You do not use either type.

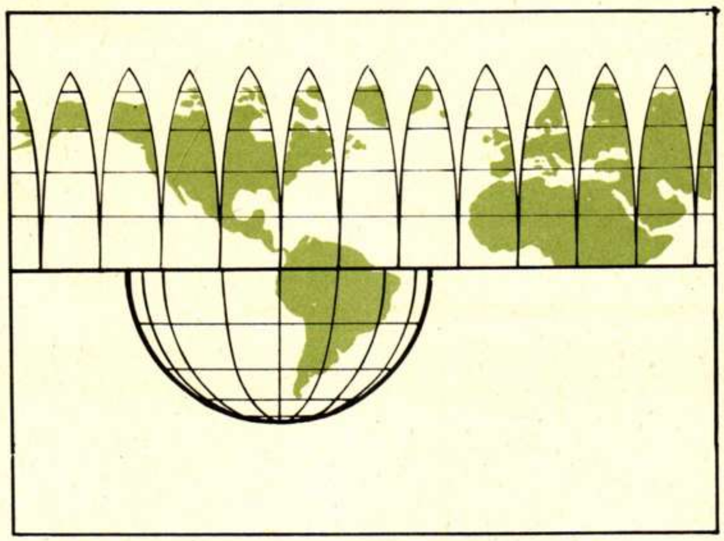
MERCATOR PROJECTION

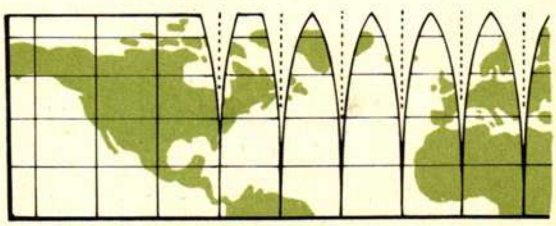


For navigation by dead reckoning, you use maps made from the **Mercator projection.** The reason is that on these maps the intersecting coordinates form a perfect grid system, that is, one where the grids are perfect rectangles. This makes plotting of positions and courses very easy.

To understand how the spherical surface of the earth is projected onto a flat surface by the Mercator system, imagine a cylinder placed around the globe in such a way that it touches all points on the equator. Then take the segment of the globe's surface lying between two meridians and "peel it back" from the poles until it stands in the plane of the cylinder, perpendicular to the equator. If you continue this "peeling" process, you have on the cylinder a series of these pointed segments. Now if you unroll the cylinder and lay it on a flat surface, you have a map of the globe.

Such a map, however, composed of a series of pieces with many gaps between, would not be very useful. To make it useful, the empty spaces must be filled in. It is this "filling in" that accounts for the distortion in a map made from the Mercator projection.





To fill in these blank spaces, the Mercator projection first straightens the meridians. This causes no distortion at the equator, because at the equator meridians 1° apart are actually 60 nautical miles apart. But as you move north or south from the equator on the spherical surface of the earth, the meridians draw closer together in miles, although the angle between them remains the same. Thus at latitude 60° N or S, the length of 1° of longitude is only 30 nautical miles on the earth's surface. At the poles the distance is zero nautical miles.

Therefore, with a Mercator projection there is no east-west distortion at the equator, but north or south of the equator east-west distortion exists. As you move north or south from the equator, the distortion increases. In the extreme north or south portions of the map, this east-west distortion becomes so great that areas appear several times as wide as they actually are.

To balance this east-west distortion which results from making the meridians parallel, the north and south dimensions are also expanded in the same proportion. In other words, the latitude scale is made proportional to the longitude scale. The result is that the parallels of latitude are not equally distant apart. As you move north or south from the equator on the map, the parallels become farther and farther apart.

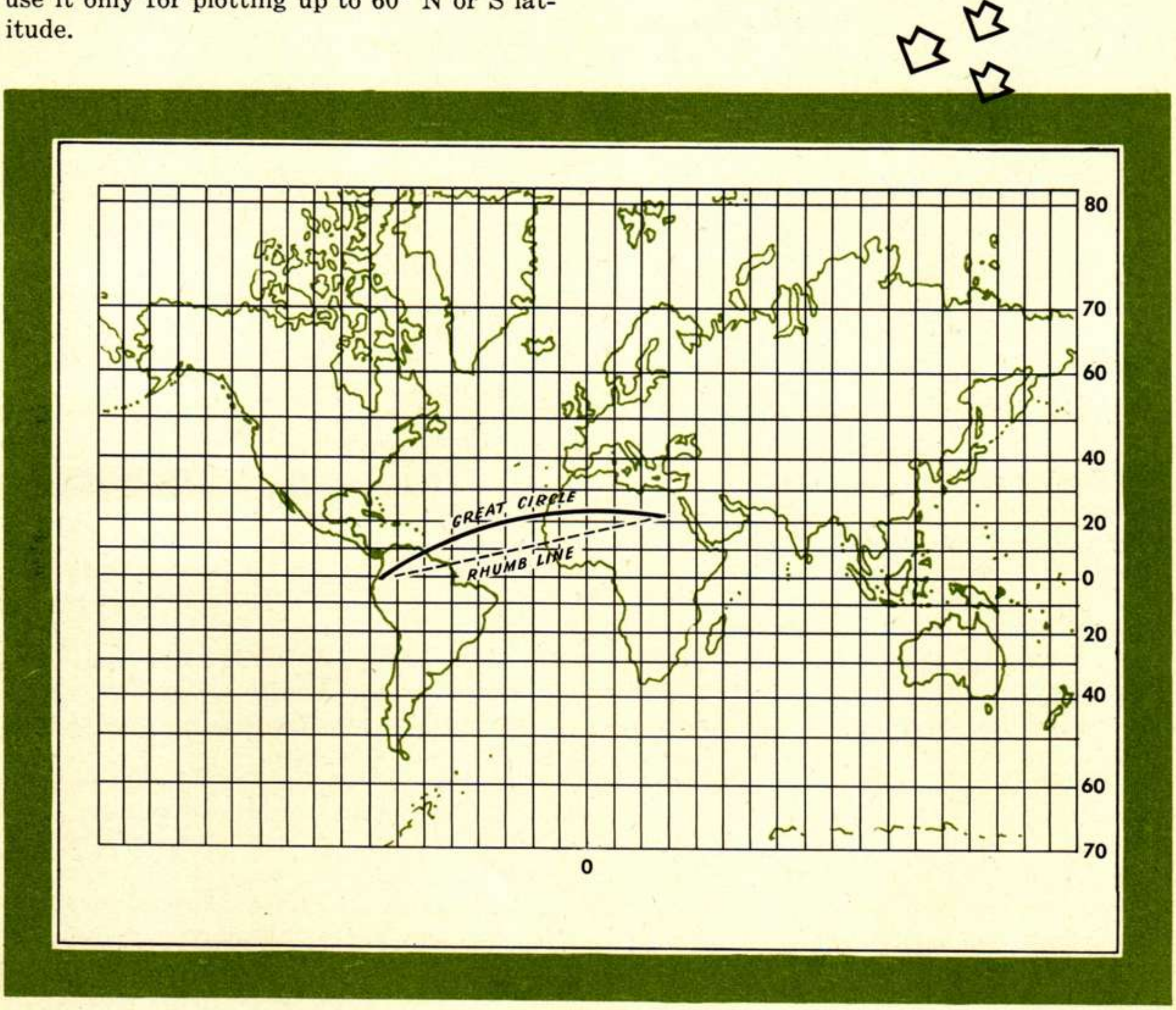
The east-west distortion plus the proportional north-south distortion produces two results which you must remember. First, since the distortion is equal in all directions, areas retain their proper shape. Second, in the northern and southern portions of the map, areas appear several times larger than they actually are.

The great advantage of the Mercator projection is that it gives you a map on which you can plot positions and courses very easily. All meridians are equidistant parallel straight lines. All parallels of latitude are non-equidistant parallel straight lines. Thus all angles formed by the intersection of meridians and parallels are 90° angles. Furthermore, any straight line drawn on the map will intersect all meridians at the same angle. This means that all rhumb lines which you use to plot your course are straight lines.

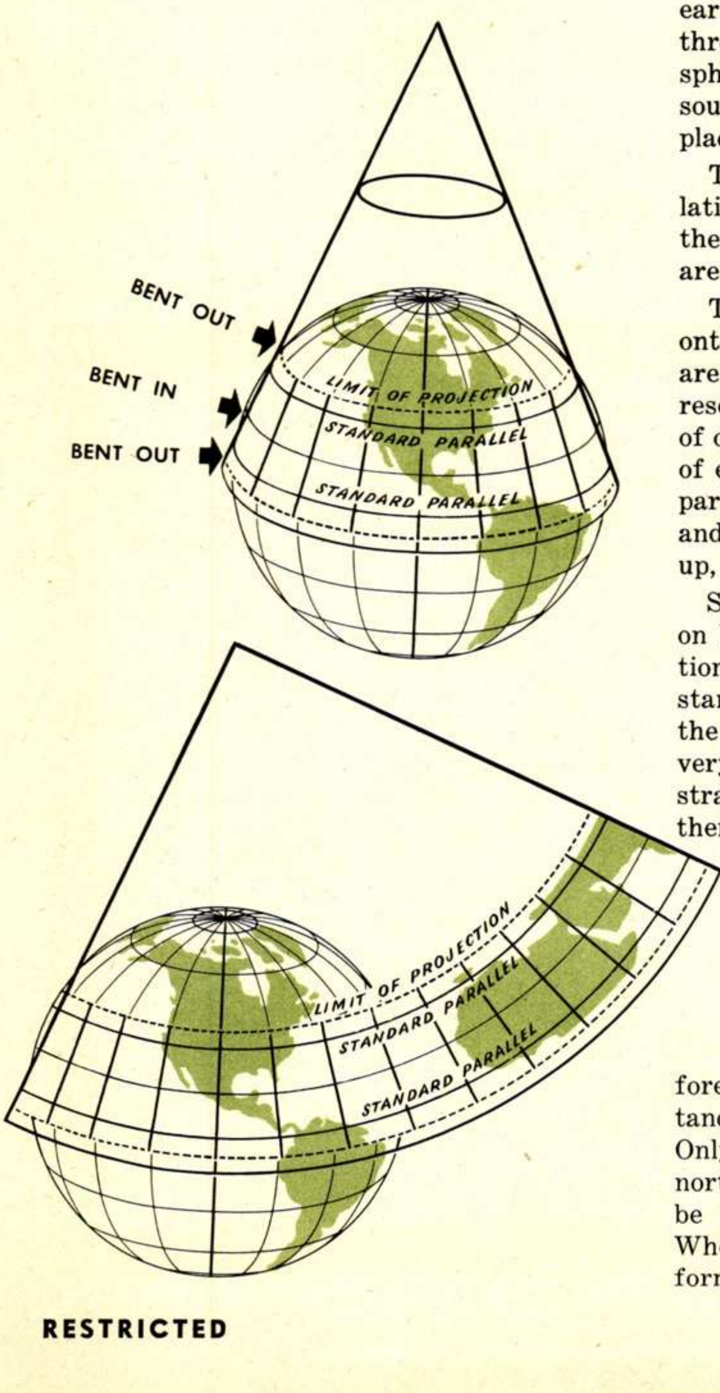
On a Mercator projection map a great circle is not a straight line; it is a curve. Therefore you must use other kinds of maps when you need to draw a great circle as a straight line. Furthermore, the great distortion makes the Mercator projection map nearly useless for the northern and southern areas. You use it only for plotting up to 60° N or S latitude.

A final disadvantage of the Mercator projection is that it gives you a map on which the distance scale varies. The parallels of 50° and 60°, for example, are much farther apart on the map than the parallels of 10° and 20°, yet the actual distance on the earth's surface is the same (600 nautical miles). Therefore when you use a Mercator projection map you have to be particularly careful to use the correct distance scale for the latitude you are plotting.

THE WORLD ON A MERCATOR PROJECTION



LAMBERT CONFORMAL PROJECTION



When you want a map with a constant distance scale and a minimum of distortion, and also one on which a great circle is approximately a straight line, you use a map made from the **Lambert conformal projection**. The sectional maps you use for pilotage navigation are made from this projection.

By the Lambert method, a portion of the earth's surface is projected onto a cone, instead of onto a cylinder. Imagine a cone with its apex or point directly above the north pole, its axis being a continuation of the earth's axis. The sides of the cone cut through a portion of the northern hemisphere. To make a map of a portion of the southern hemisphere, the apex of the cone is placed over the south pole.

The intersections occur at two parallels of latitude. Any two parallels may be selected as the points of intersection. These two parallels are called the **standard parallels**.

To project the curving surface of the earth onto the surface of the cone, the meridians are first straightened, so that each line representing a meridian lies on the cone instead of on the sphere. This means that the portion of each meridian lying between the standard parallels is flattened. The portions lying north and south of the standard parallels are bent up, away from the surface of the sphere.

Since the standard parallels are the same on both sphere and cone, there is no distortion of the map at those parallels. If the standard parallels used are close together, the arc of the meridian between them is a very slight curve. When it is flattened into a straight line the distortion that results is therefore small. If the standard parallels are farther apart, the distortion in that portion of the map lying between them is greater.

In the portions of the map outside the standard parallels, the meridians are bent up through greater and greater arcs. Therefore, the distortion becomes greater as distance outside the standard parallels increases. Only a small portion of the earth's surface north and south of the standard parallel can be projected without too great distortion. When a map is made from the Lambert conformal projection, four-sixths of it is between the standard parallels, one-sixth is above the upper standard parallel, and one-sixth is below the lower one. The projection is used only for maps showing sections of either the northern or southern hemisphere.

When the meridians are drawn as straight lines on the cone, they converge at the point or apex of the cone. When the section to be mapped is unrolled from the cone and laid on a flat surface, the meridians appear as straight lines which converge at a point outside the map. The parallels of latitude are arcs of concentric circles. They intersect all meridians at a 90° angle.

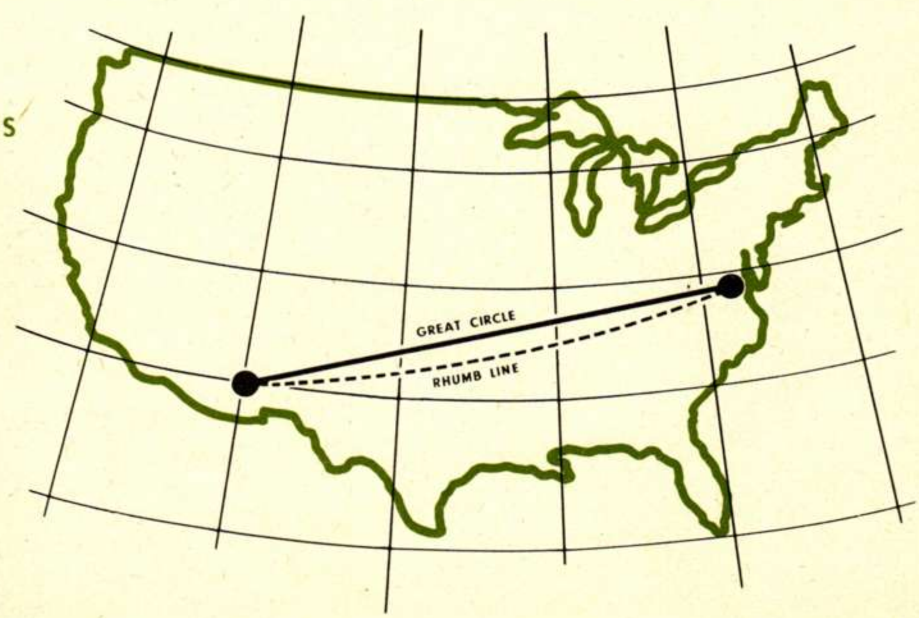
Since the meridians are not parallel, a straight line drawn on the map will not intersect all meridians at the same angle. Therefore, on a map made from the Lambert conformal projection, a rhumb line is not a straight line; it is a curve. A great circle, on the other hand, is approximately a straight line.

When an airplane flies on a constant heading, the path of its flight crosses all meridians on the earth's surface at the same angle. That is, the airplane flies a rhumb line course. If you draw a **straight** line between two points on a Lambert map, the angle between the straight line and the meridian of the point of departure is not the same size as the angle between the straight line and the meridian of the destination point. Therefore, you take the angle formed by the intersection of the straight line and the meridian halfway between the meridians of departure and destination. This is called the **mid-meridian** angle. You use this mid-meridian angle as your course angle. The path of your flight on this course is a rhumb line.

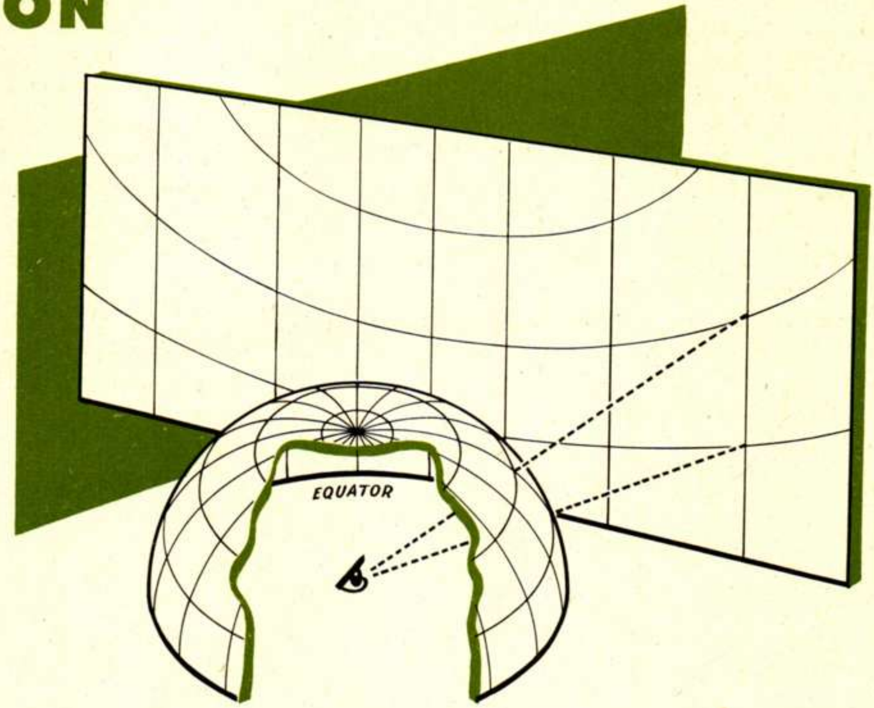
When you fly this mid-meridian course, the path of your airplane will not be the straight line on the Lambert map joining point of departure and destination. Instead it will be a slight curve. In other words, you do not fly directly over landmarks that are on that straight line, but slightly to one side of them. But when you fly short distances, as you will on your navigation missions, this deviation at your various check points is small. For flights of less than three or four hundred miles, you can disregard it.

Although plotting is more difficult on the Lambert map than on the Mercator, the Lambert does have the advantage of a constant distance scale because meridians and parallels have the same relation to each other as they have on the globe. In other words, one minute of latitude, or one nautical mile, is the same length anywhere on the chart. Furthermore, areas are represented on a Lambert map in very nearly their true shape and size, because there is so little distortion.

THE UNITED STATES ON A LAMBERT PROJECTION



GNOMONIC PROJECTION



Maps made from the **gnomonic projection** are used chiefly as aeronautical planning charts. To make a gnomonic projection, a portion of the earth's surface is projected onto a plane which touches the earth at one point only. At the one point where the plane touches the sphere there is no distortion. Away from this point in any direction there is distortion. It becomes extreme at the edges of the map.

Imagine yourself standing under a large glass dome representing the northern hemisphere. On the dome, at 10° intervals, lines are painted and labeled as the meridians and parallels. The equator is represented by the line where the dome touches the ground. If you stand in the exact center of the dome, the meridian lines converge directly over your head at a point which represents the north pole.

Now imagine a wall built outside the dome, perpendicular to the ground and touching the dome at one point only, for example the point where the line representing the prime meridian touches the ground. If you place a strong light at the center of the globe, you see on the wall the shadow of this prime meridian line. The shadow is a straight line perpendicular to the ground, starting at the point where the sphere touches the wall and stretching up to infinity.

If you now face the line representing the meridian of 10° E, you see another shadow on the wall. It is also a straight line, perpendicular to the ground and stretching upward to infinity. The same thing is true of the shadows cast on the wall by the other meridian lines.

The meridian lines are equidistant around the base of the dome. But the shadows are not equidistant on the wall, because the light travels out from the dome towards the wall in straight lines radiating from the center of the dome.

Therefore, when a gnomonic projection is made onto a plane which touches the sphere at the equator, the meridians appear as non-equidistant, parallel, straight lines.

In the same way, the lines representing parallels of latitude cast shadows on the wall. The shadow of the equator appears as a straight line lying along the base of the wall.

The parallel of 10° N will cast a shadow shaped like a shallow arc with the ends pointed up. The reason for this shape is again that the light radiates out from the center of the dome in straight lines. For the same reason, the shadow is farther from the shadow of the equator than the distance between the two lines on the dome.

The shadow cast by the parallel of 20° N is another arc, but it is less shallow and is still farther from the shadow of 10° N. The same thing is true of the other parallels. The higher your latitude, the greater the curve of your arc and the farther from one arc to the next.

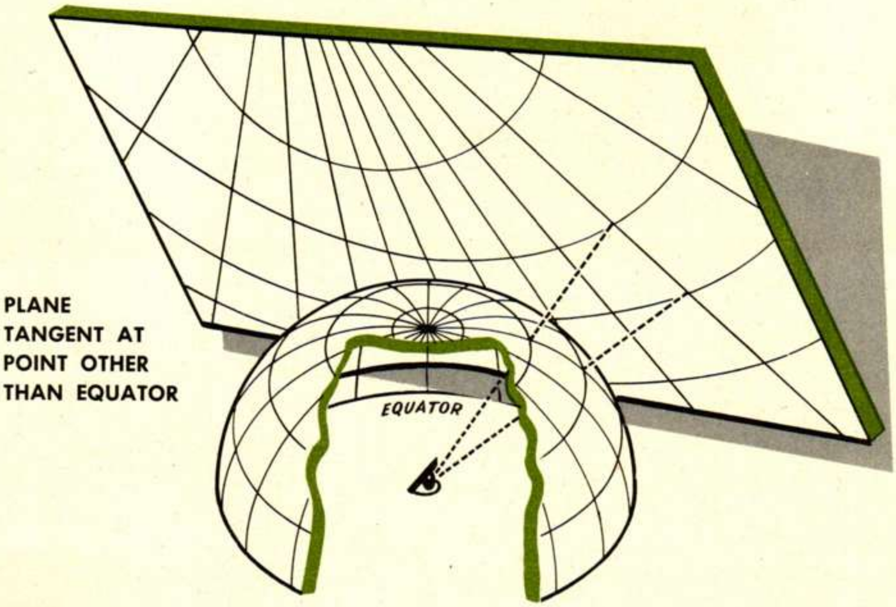
Thus, when a gnomonic projection is made onto a plane which touches the sphere at the equator, the parallels of latitude appear as non-equidistant, non-concentric curves.

To understand what happens when a gnomonic projection is made onto a plane which touches the sphere at some point **not on the equator**, rotate the dome so that the north pole, instead of being directly over your head, is at a point 45° above the ground. Now the shadow of the prime meridian is again a straight line on the wall, perpendicular to the ground. At a certain point up the wall on this shadow the north pole appears.

The shadow of the meridian of 10° E is also a straight line on the wall, but it is not perpendicular. Instead, it converges toward the shadow of the prime meridian, and intersects it at the point representing the north pole. Similarly, the shadow of meridian 20° E is a straight line but shows still greater convergence, for it, too, intersects the prime meridian at the pole.

Thus, when a gnomonic projection is made onto a plane which touches the sphere at some point **not on the equator**, the meridians appear as **converging straight lines**.

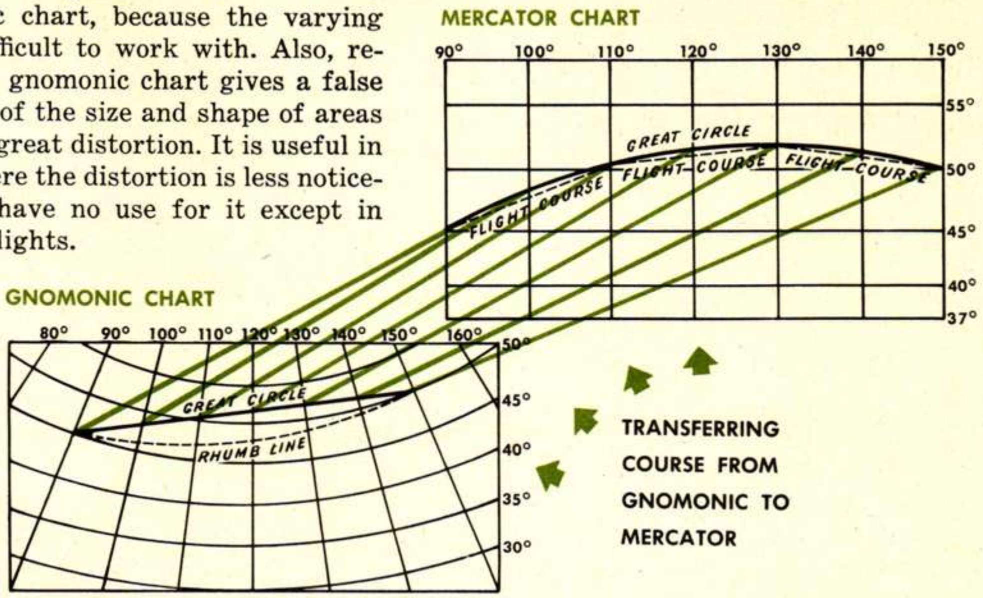
The parallels of latitude are projected as non-equidistant, non-concentric circles.



On a gnomonic chart, the parallels and meridians intersect at a variety of angles. A rhumb line, which must cut all meridians at the same angle, is therefore not a straight line but a curve.

A great circle is a straight line. This is the great advantage of the gnomonic chart. Since the shortest distance between two points on the earth's surface is a great circle, you can plan a long flight very easily. Connect your points of departure and destination with a straight line (great circle) on a gnomonic chart, and note the coordinates at selected points along this line. Then transfer these coordinates to a Mercator chart and connect them with straight lines. These straight line segments are the rhumb line segments of the course you will fly.

You do not attempt to measure distances on a gnomonic chart, because the varying scale is too difficult to work with. Also, remember that a gnomonic chart gives a false representation of the size and shape of areas because of the great distortion. It is useful in polar areas where the distortion is less noticeable, but you have no use for it except in planning long flights.



Conditions	Mercator	Lambert Conformal	Gnomonic
Projected by	Cylinder tangent at equator	Cone secant at standard parallels	Tangent plane eye at center
Parallel of latitude	Non-equidistant parallel straight lines	Arcs of concentric circles	Curved lines
Meridians	Equidistant parallel straight lines	Converging straight lines	Converging straight lines
Angle between parallel and meridian	90°	90°	Varies
Rhumb line	Straight line	Curve	Curve
Great circle	Curve	Straight line (approximately)	Straight line
Angle straight line makes through meridian	Constant angle	Varies	Varies
Distance scale	Measured mid-latitude	Constant	Must be calculated
Advantages	Rhumb line straight Grids rectangles (easy plotting) True shape in small areas Used in precise navigation	Constant distance scale Small distortion Great circle a straight line (approximately) Used as basis for sectional maps	Great circle a straight line Useful in polar areas Used also to plan air routes
Disadvantages	Distortion above 60° Scale varies Great circle not straight line	Plane does not fly over points in Rhumb line Plotting more difficult Course measured mid-meridian	Scale difficult to work with Much distortion

MAPS AND MAP READING

After centuries of development, the science of map-making can now produce maps which give you an almost perfect representation of an area as it looks to you when you fly over it. The maps you use show landmarks very clearly. They also give you other information which helps you to navigate successfully.

In pilotage navigation you use three types of maps: sectional maps, regional maps, and radio direction finding charts (RDF). All three are Lambert conformal projections.

A **sectional map** is a map of a comparatively small section of the earth's surface. It is made on a large scale: **1 inch** on the map represents only 8 **nautical miles**. There are 87 sectional maps covering the area of the United States. Because of the large scale, landmarks are shown in such detail that you can recognize them easily.

Regional maps cover a large region instead of a small section. It takes only 17 of these charts to map the area of the United States. The scale is much smaller than the one used on a sectional. On a regional map, 1 inch represents 16 nautical miles on the ground. Although landmarks are easily recognized, the regional map shows much less detail because of the smaller scale. Many landmarks shown on a sectional map do not always appear on a regional.

On short flights you generally use a sectional map. If you are flying over a large region it is easier to handle one regional map than three or four sectional maps.

A **radio direction finding chart** (RDF) is used to plot radio bearings, when you navigate by radio aids. You can use an RDF chart as you use a regional map, disregarding the radio information on it. However, there are few details on an RDF chart, because it is made on a very small scale. One inch on an RDF chart represents 32 nautical miles on the ground. The entire area of the United States is shown on six of these charts.

Map Reading

In order to read maps accurately, you must know the conventional symbols that are used to represent different features on the earth's surface. There are four kinds of features shown on sectional and regional maps, and each kind is shown in a different color.

1. **WATER** (streams, lakes, canals, etc.) Represented in *blue*.

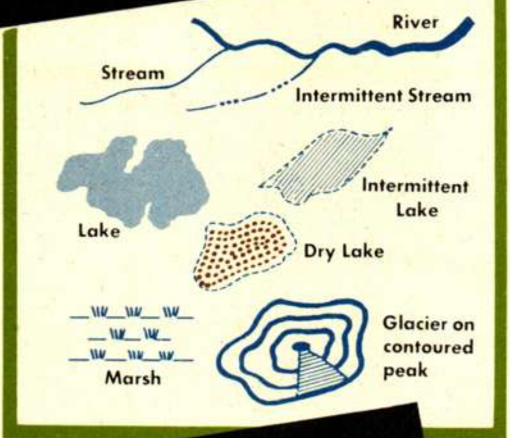
2. **CULTURE** (man-made features, such as towns, roads, railroads). Generally represented in *black*.

3. **RELIEF** (topographical variations, such as hills, valleys). The general elevation of a particular small area is indicated by the color in which it is printed. Land areas at sea level are shown in *green*. Areas above 9,000 ft. are shown in *dark brown*. Intermediate elevations are indicated by *shadings of light green* and *tan*. Specific elevations are shown by contour lines in brown.

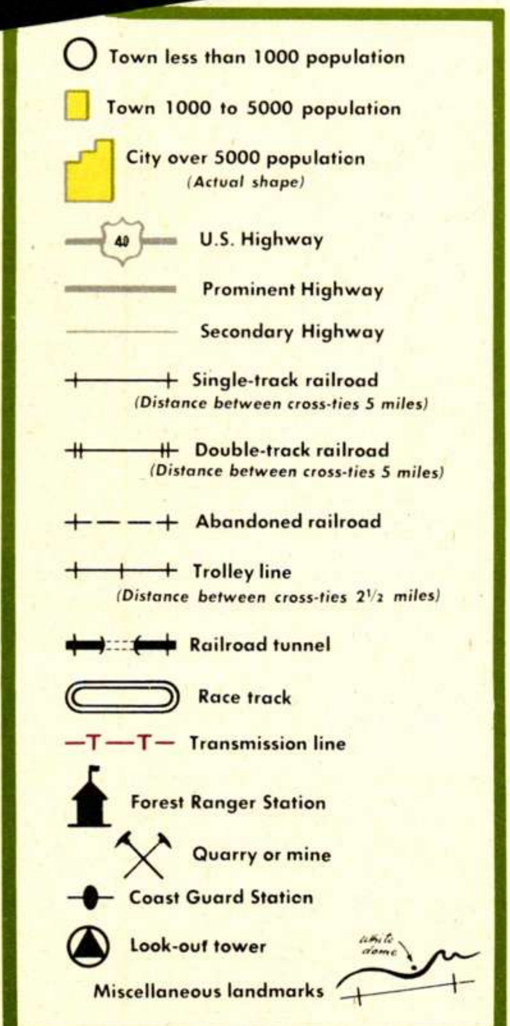
4. **AERONAUTICAL INFORMATION** (airway beacons, airports, radio range, etc.). Printed in *red* or *dark blue*.

Within these four groups there are a number of different symbols used to represent specific features. Here are the principal symbols you must learn to identiy:

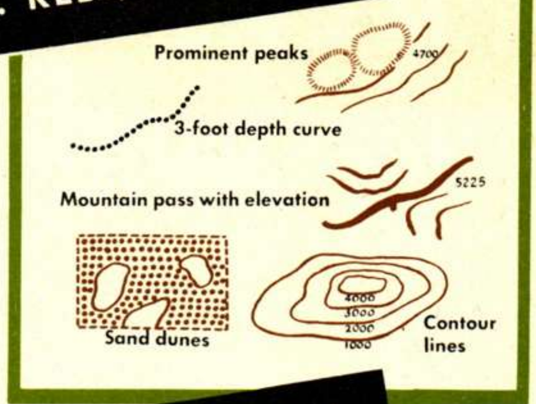
1. WATER SYMBOLS



2. CULTURE SYMBOLS



3. RELIEF SYMBOLS

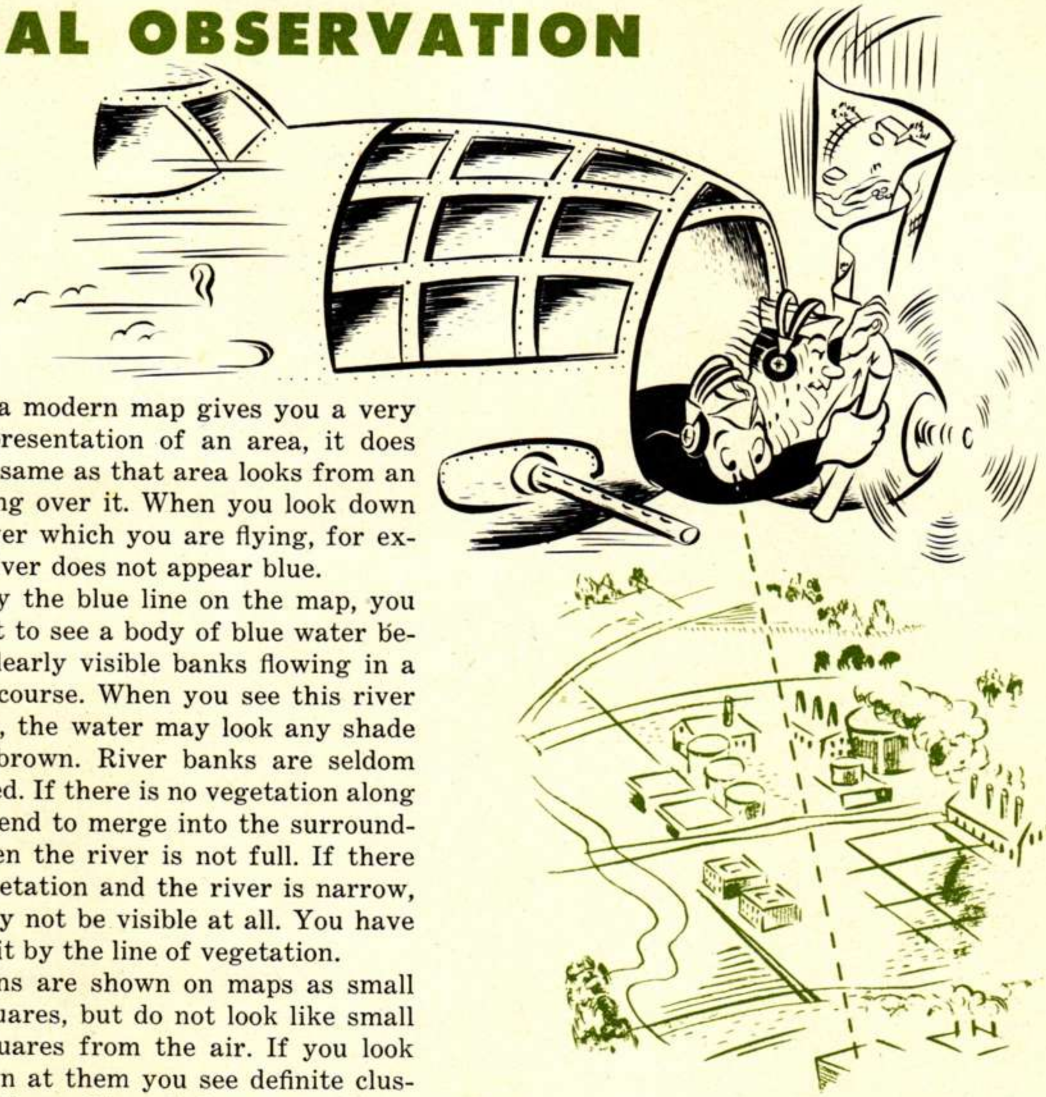


4. AERONAUTICAL INFORMATION

There are other symbols for less common features but they will either be labeled or designated on the sectional map.

In the bottom margin of the sectional map you will also find such additional data as title, type of projection, date of publication, and an index to sectional charts adjoining the particular one with which you are concerned.

MAPS AND AERIAL OBSERVATION



Although a modern map gives you a very accurate representation of an area, it does not look the same as that area looks from an airplane flying over it. When you look down at a river over which you are flying, for example, the river does not appear blue.

Judging by the blue line on the map, you might expect to see a body of blue water between two clearly visible banks flowing in a well-defined course. When you see this river from the air, the water may look any shade of gray or brown. River banks are seldom clearly defined. If there is no vegetation along them, they tend to merge into the surrounding land when the river is not full. If there is heavy vegetation and the river is narrow, the river may not be visible at all. You have to recognize it by the line of vegetation.

Small towns are shown on maps as small circles or squares, but do not look like small circles or squares from the air. If you look straight down at them you see definite clusters of buildings. Viewed from an oblique angle a small town may blend into the surrounding country and you may not recognize it.

Furthermore, several small towns in the same area usually look very much alike. If you try to identify one of them by noting that the map shows three roads intersecting in it, you may see that there are actually five or six roads passing through each of the towns. Small unimproved roads are not shown on the map, but they show up very clearly from the air. You can identify the towns only by learning to pick out accurately the landmarks shown on your map, ignoring features that are not shown.

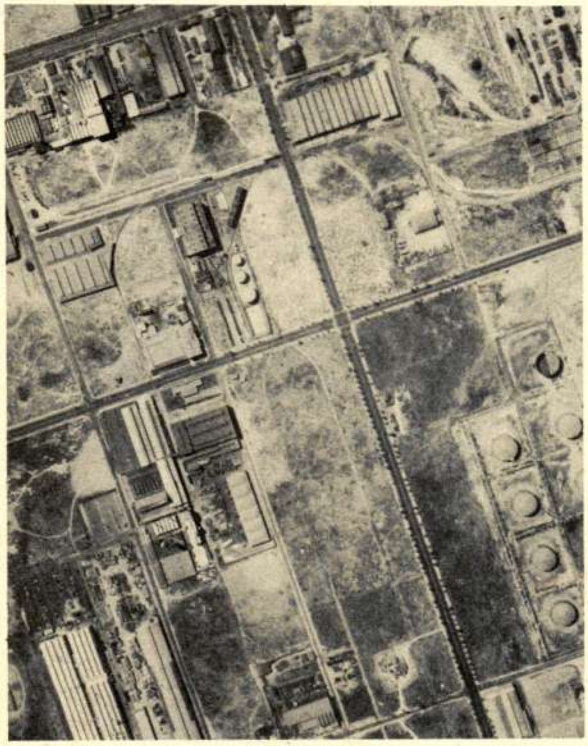
A good way to train yourself for aerial observation is to compare a map of a given area with an aerial photograph of the same area. Such a comparison shows you how differently the area appears in the two representations. In studying these maps and photographs, remember that the photograph does not show you everything you would see from an airplane flying above the area. The photograph shows only a small area. It shows accurately what you would see if you could limit the focus of your eyes to that area, but when you look down from an airplane you actually see a far larger section of the earth's surface.


Throckmorton
Elm
Cr
TRUE NORTH
Res
M K & T
82
Saint Jo
Water tank
TRUE NORTH
TRUE NORTH
300
330
5-Span bridge
New Castle
1164
7-Span bridge
6-Span bridge
LF
6 G
TRUE NORTH

TARGET IDENTIFICATION

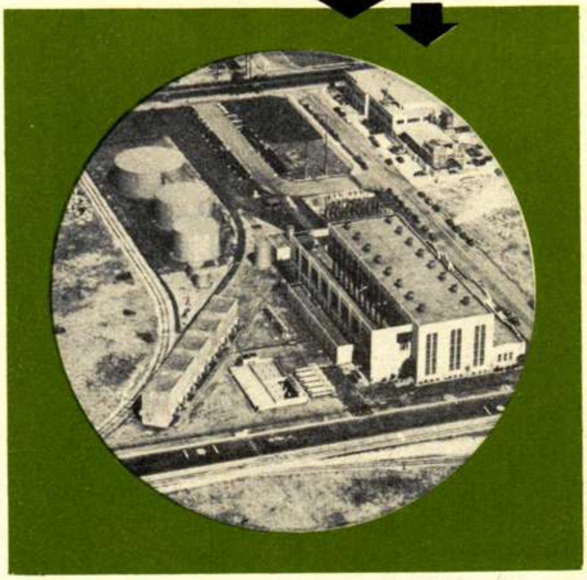
In order to carry out a bombing mission, you must first be able to navigate to the target area by pilotage or dead reckoning. But to do **precision bombing**, you must be able to **identify the specific target** within the general target area and set your sight squarely on it. To do this successfully you must train your eyes to recognize objects on the ground from many altitudes and angles of vision. You must also learn to concentrate on prominent landmarks and mentally blot out many confusing details.

Experience is the only thing that will make you skillful in target identification. Your best teacher is your own constant practice. You **must** practice observation and identification at every opportunity. You cannot learn it on the ground. You will actually learn it only by long practice in the air.



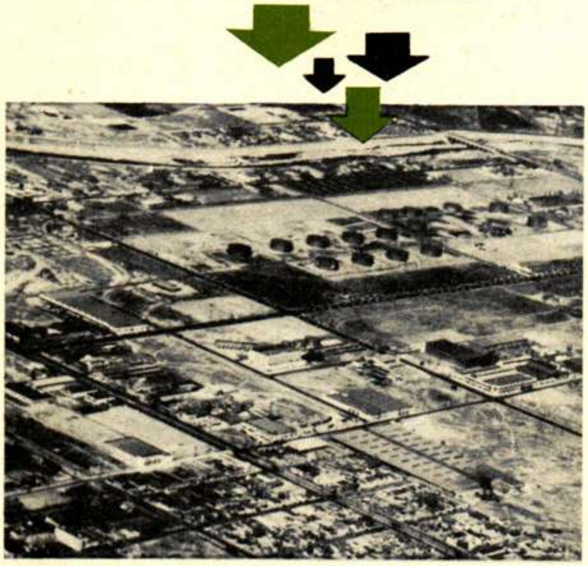
From the study of aerial photographs, however, you can learn a few common-sense methods that will help you progress faster in your practice.

To give you some idea of your problem, here is a vertical photograph of a target. This is the way it looks when you are directly over it.

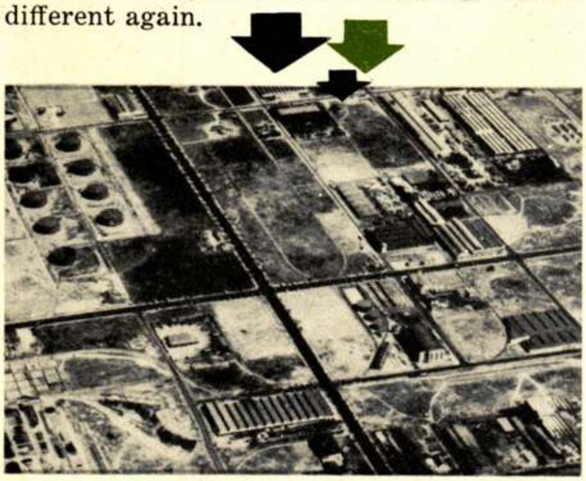


Remember, however, that this photograph has been focused on the target. It does not show the surrounding area, which you see from the air. You must be able to pick out the target in a large area.

It is comparatively easy to pick out the target when you are vertically over the area. But you cannot wait until you are directly over your target to begin your work on the bombsight. You must be able to pick up the target when you are still a long distance away from it, in order to set your sight. When you turn in to the target to begin the run, you must be able to pick up the target instantly. At this point you see the target area at an oblique angle, and it looks quite different from a vertical photograph.



If you come in on another heading, it looks different again.



Finally, remember that different altitudes give you different angles of vision. Even on the same heading, an area looks different from 4,000 ft. than it does from 25,000 ft.

PATTERNS AND REFERENCE POINTS

When you look down at any area on the land surface of the earth, the natural and man-made features in that area form a **pattern**. A pattern is simply a design. Intersecting straight lines, like the streets of a modern city, form a checker board or grid pattern. Curving lines intersecting straight lines may form patterns like wheels or spider webs. Rivers and twisting canals may form irregular, curving patterns.

A sense of pattern helps you to identify targets from the air. Study the vertical photographs of the target area you are given in the briefing room. Fix clearly in your mind the pattern formed by various features in the target area. Notice carefully where a prominent straight line, such as a section of railroad, crosses the curving line of a river.

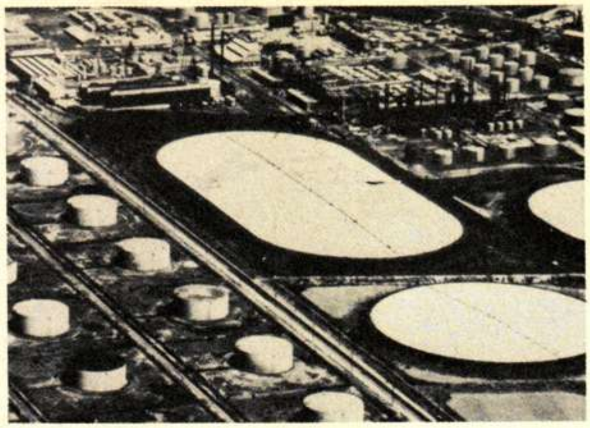
Study also the shapes of different buildings. The round shapes of storage tanks are easy to identify. Try to become familiar with the usual forms of warehouses, powerplants, and other targets. You need to fix in your mind the shape of your target, and the differences between it and surrounding buildings.

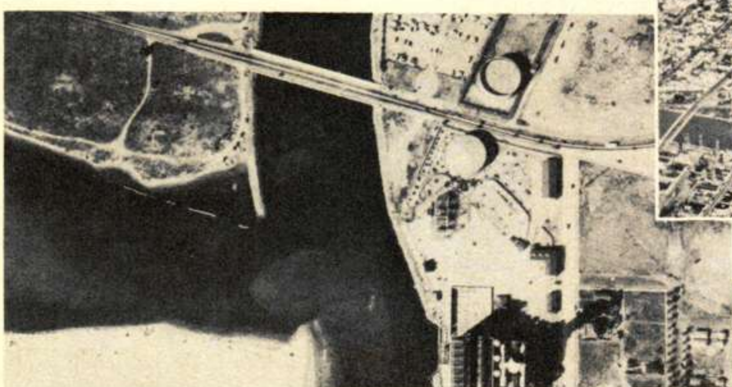
Once the pattern of the target area is clearly fixed in your mind, note the **position of the target in that pattern**. The general pattern is made up of a group of specific features, such as highways, parking lots, railroads, and buildings. Use these various features as **reference points**, and see **where your target is in relation to each of these reference points.**

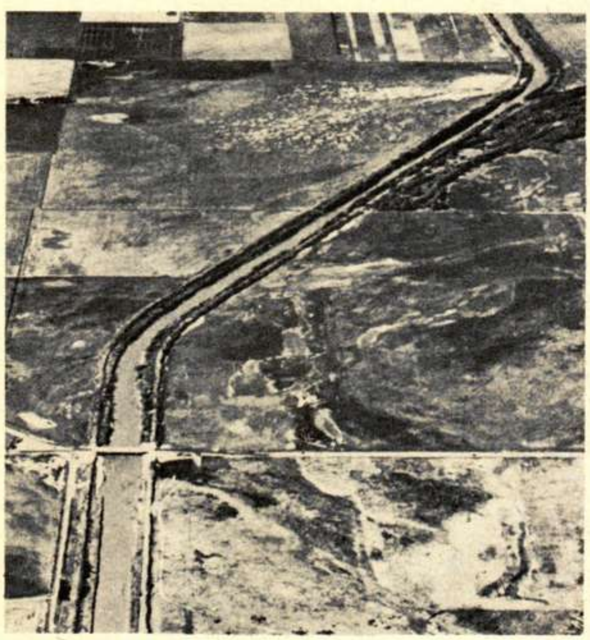
In choosing the reference points you intend to use, be sure you select **prominent** features which will stand out clearly as you look down toward the area. A reference point should be so clear you cannot miss it. A large feature is usually better than a small one.

Pick features that have **distinctive shapes.** Such things as railroad roundhouses, small lakes and reservoirs, open air stadiums, oil tanks, and railroad yards make excellent reference points. They show up plainly from all practical altitudes and their forms are clear and distinct. In a harbor area, use docks, breakwaters, and warehouses. In rural areas, prominent features are harder to find, but you can use as reference points rivers, lakes, roads, and even fields to get your pattern.

To make a good reference point, a feature should also be **unusual**. For example, if your target lies in the middle of a grid formed by city streets, do not try to use one of those parallel streets as a reference point. Instead, try to find a curving line, or some heavy straight line that intersects at an angle. If you select as a reference point the intersection of two railroads, look over the whole target area and be sure there is not another similar intersection elsewhere in the area.







If you select prominent and unusual reference points with distinctive shapes, you should be able to fix in your mind the pattern formed by these reference points in the target area. Then if you have a clear mental picture of your target within that pattern, so that you know where it is in relation to two or more reference points, you can find the target quickly at the start of the run.

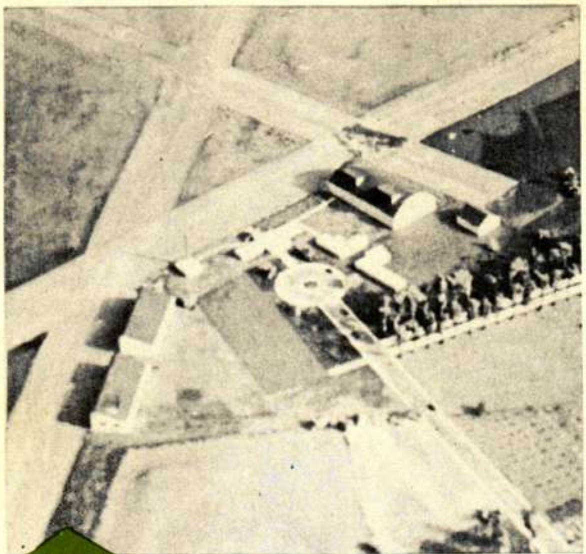
CAMOUFLAGE

By skillful camouflage, the enemy can destroy or change the pattern of a target or even of a whole target area. When you arrive at the beginning of your run over an industrial target area, you may find that camouflage has made it look like a forest or a rural area. You may find that the enemy has concealed not only the target, but also the reference points surrounding the target which you had planned to use. Your problem is to outwit the enemy's camouflage experts.

To do this, you must make your plans before taking off. Do not start out with only one pattern and one set of reference points. Select several sets of reference points, each set farther away from the target. The enemy may disguise an industrial area, but he cannot disguise a whole region. Use your closest set of reference points if they are visible. If not, use the next closest set.

In the second place, remember that the best camouflage is not perfect. Some features are very difficult, if not impossible, to conceal. Train your eyes to look at a camouflaged area and pick out these unhidden details. You may not be able to see a complete factory, for example, but you can usually see high smokestacks if you look closely.

Remember also that the enemy knows you will try to use as reference points features which are prominent, distinctive, and unusual. He will try to disguise them as well as the target. You must therefore have clearly in mind not only the good reference points you hope to use, but also other reference points which are not as good. The enemy will not disguise poor reference points so carefully.



THIS IS YOUR TARGET—
CAN YOU RECOGNIZE IT HERE?

Frequently the enemy tries to conceal the vital areas from you by setting up dummy targets and false reference points. Such features as the Eiffel Tower in Paris, the Pyramids near Cairo, and the Imperial Palace in Tokio are unmistakable reference points. The enemy may try to fool you by setting up replicas of such obvious features miles away from their actual location. To outwit him, use your head. Check the apparent reference point by **cross-reference** to other known features. Do not be too ready to believe your eyes. And be particularly suspicious of obvious reference points not camouflaged.

SCALE

It is often useful to have in mind a **scale** which you can use in computing the size of features in your target area. If your target is a warehouse 100 ft. by 500 ft., for example, there may be many similar looking buildings of various sizes in the area. You should be able to find the correct one by recognizing its size. In your practice observations, you must try to develop a sense of scale.

The easiest way to compute the size of an object is to compare it with another object whose size you know. There are two kinds of objects you can use for your unit of measurement. One is a specific feature whose exact or approximate size you know before your take-off. The other is some man-made object which is generally built in a standard size.

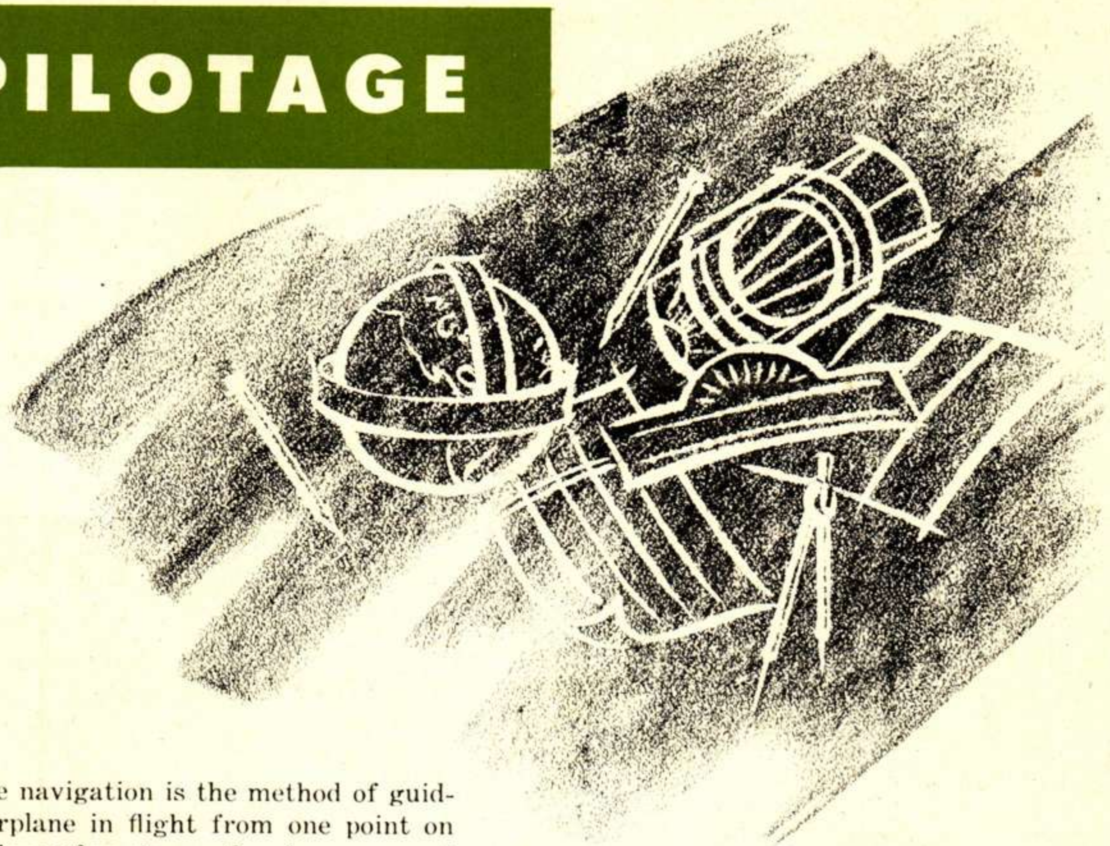
The specific object may be some well-known landmark, such as London Bridge, Unter den Linden street in Berlin, or the Arc de Triomphe in Paris. You can get the exact length and width of landmarks like these in your briefing room. You can also know the exact measurements of outstanding buildings, such as the cathedral in Cologne. If you are good at identifying ships, you can get the measurements of a given class or type.

Many man-made features are built in more or less standard sizes. A two-lane highway, for example, is usually some 20 to 25 ft. wide. On a standard-gage railroad the rails are approximately 5 ft. apart. Box cars, trucks, tanks, and automobiles are usually built in fairly standard sizes. Such things as fuel storage tanks can often be used as units of measurement.

Finally, you can obtain in the briefing room an accurate scale for the vertical photographs you use. Using this scale, estimate the size of your target and of various reference points before take-off.

A sense of scale is of great importance in picking out your specific target. You also need to estimate distances as accurately as possible in order to find your reference points and to locate your target with respect to them.

PILOTAGE



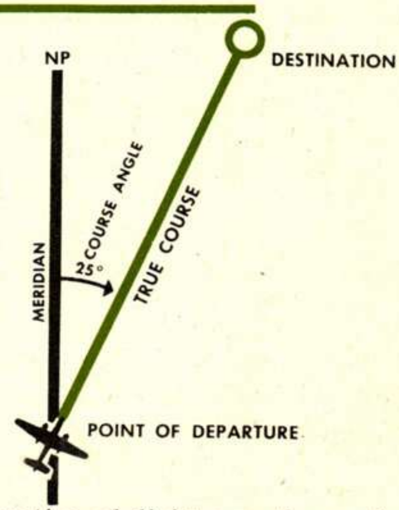
Pilotage navigation is the method of guiding an airplane in flight from one point on the earth's surface to another by means of direct observation of the ground. You locate your airplane by recognizing landmarks over which you fly and determining your position in relation to them.

In pilotage you use charts, certain plotting instruments, and a log book. Naturally you use pilotage only in navigating over areas that contain clearly visible landmarks, such as towns, rivers, mountains, or airway beacons.

TERMS USED IN PILOTAGE TECHNIQUE

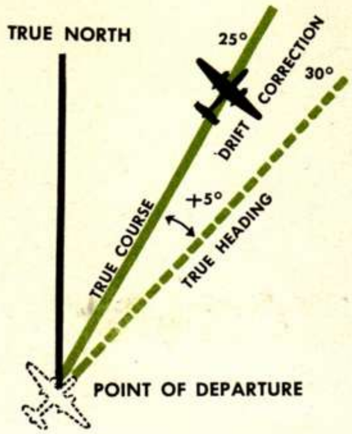
In your pilotage procedures you must have clearly in your mind a number of terms which you have already learned in your study of instruments and in your bombing work. As a reminder, here are the definitions of the principal terms you will use.

TRUE COURSE (TC)



The direction of flight over the surface of the earth, expressed as an angle with respect to true north. Course is always true course unless otherwise designated. It is the course laid out on the chart or map. All courses are measured clockwise from true north through 360°. True course made good may be called "track."

DRIFT CORRECTION (Dr. Corr.)

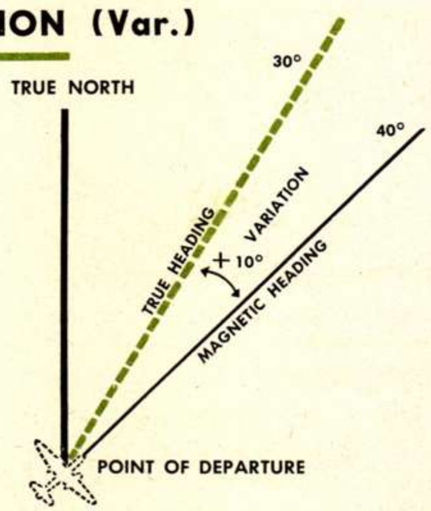


The angle added to or subtracted from an airplane's true course to obtain true heading. When you have right drift, SUBTRACT the angle from the true course to obtain the true heading (**minus** Corr.); when you have left drift, ADD the angle (**plus** Corr.).

TRUE HEADING (TH)

The direction of the longitudinal axis of the airplane, expressed as an angle with respect to true north. In other words, it is the true course with the drift correction applied. Heading is always true heading unless otherwise designated.

VARIATION (Var.)

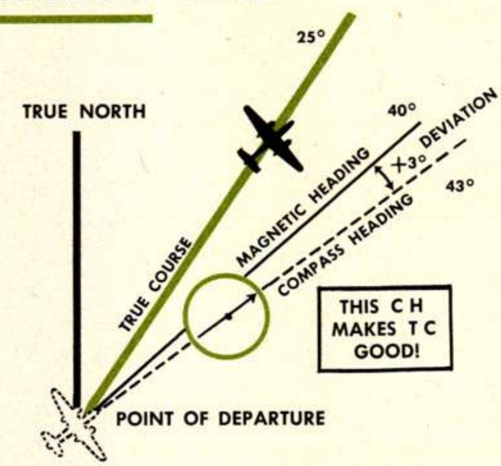


The angle between a line to true north and a line passing through a freely suspended compass needle influenced solely by the earth's magnetism. It is the angle between lines to true north and magnetic north. It is named east or west according to the direction of the compass needle from true north.

MAGNETIC HEADING (MH)

True heading with variation applied. The direction of the longitudinal axis of the airplane, expressed as an angle with respect to magnetic north. If the variation is **west** ADD **variation** to true heading to obtain magnetic heading. If variation is **east** SUBTRACT.

DEVIATION (Dev.)



The angle between a line to magnetic north and a line passing through a compass needle. Deviation is caused by magnetic influences in the airplane. It is named east or west according to the direction in which the needle is deflected from magnetic north.

COMPASS HEADING (CH)

Magnetic heading with deviation applied. If the deviation is **west**, ADD deviation to magnetic heading to obtain compass heading. If deviation is **east**, SUBTRACT.

INDICATED ALTITUDE

The altitude indicated by the altimeter.

CALIBRATED ALTITUDE

Indicated altitude corrected for instrument and installation errors.

PRESSURE ALTITUDE (PA)

Calibrated altitude when the pressure scale is set at 29.92.

TRUE ALTITUDE

Actual height in feet above sea level.

ABSOLUTE ALTITUDE

Actual height in feet above the earth's surface.

INDICATED AIRSPEED (IAS)

The reading of the airspeed indicator in **mph**.

CALIBRATED AIRSPEED (CAS)

The reading of the airspeed indicator, corrected for instrument and installation error. In bombing, "miles per hour" is generally used; for navigation, "knots" (nautical miles per hour). For the latter purpose, indicated airspeed is calibrated and converted to knots in one operation by reading the appropriate column on the airspeed meter calibration card.

TRUE AIRSPEED (TAS)

The true speed of an airplane relative to the air. Airspeed is always true airspeed unless otherwise designated. Airspeed is obtained by correcting the calibrated airspeed for density, using temperature and pressure altitude corrections.

GROUNDSPEED (GS)

Actual speed of an airplane relative to the earth's surface.

WIND DIRECTION

The direction **from which** the wind blows.

WIND SPEED

The speed of the wind, expressed in mph or in knots. For navigational purposes, use knots.

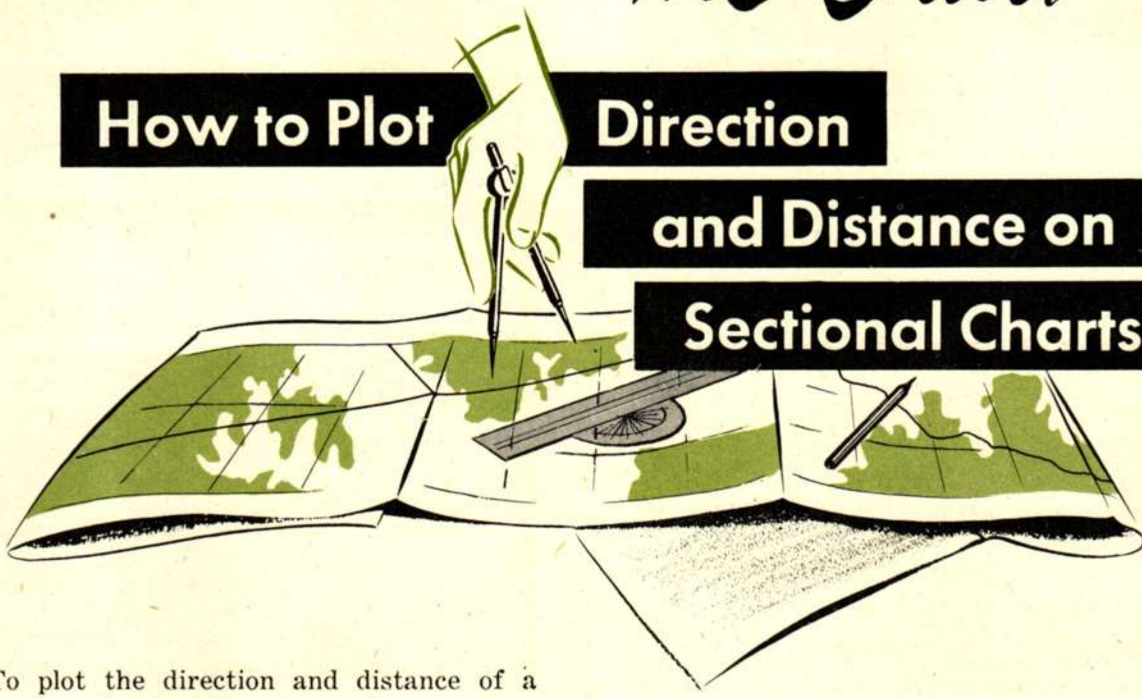
ESTIMATED TIME OF ARRIVAL (ETA)

In addition to these familiar terms, you need to understand one new one: **Estimated Time of Arrival** (ETA). This is simply the time at which you should arrive over a given point, according to your calculations.

PILOTAGE PROCEDURE

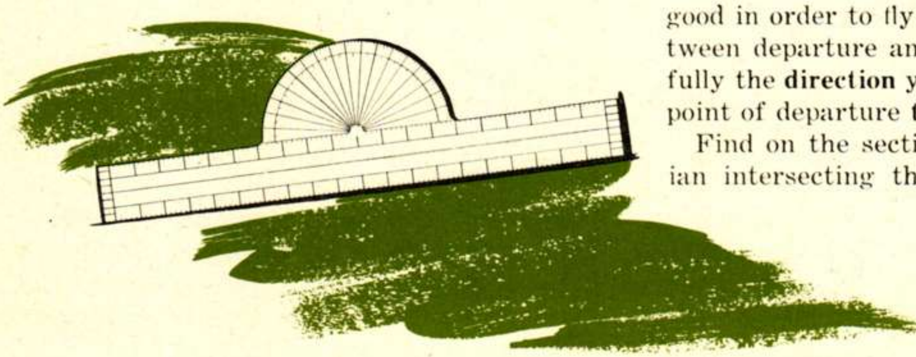
The Chart

How to Plot Direction and Distance on Sectional Charts



To plot the direction and distance of a course on sectional or regional maps, you use a **plotter** and a pair of **dividers**. The plotter is a combination ruler and protractor, and is made of transparent material. On the face of the ruler portion of the plotter four scales are printed. The two outer scales correspond to statute miles on regional charts; the two inner scales correspond to statute miles on sectional charts.

The semicircular portion contains two scales, graduated in all 360 degrees of the compass. The **outer** scale extends from 0° to 180°; the **inner** scale from 180° to 360°.



You use these semicircular scales to measure course angles. At the center of each scale there is an arrow, the outer one pointing **to** the right and the inner one to the left. These indicate the **direction of course.**

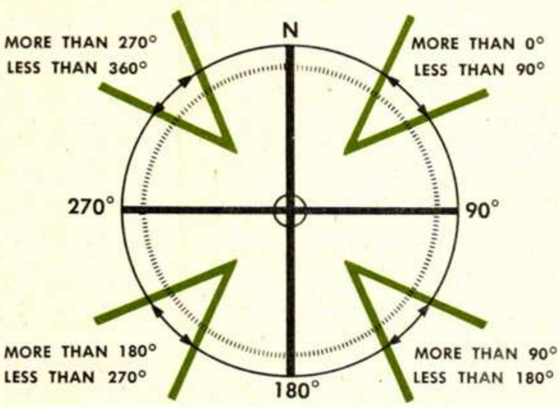
To Determine a Course Angle

Locate the coordinates of departure and destination on your sectional map. With the ruler portion of the plotter, draw a straight line connecting these two points. This line is your intended course which you must make good in order to fly the shortest distance between departure and destination. Note carefully the **direction** you intend to fly, **from** the point of departure **to** destination.

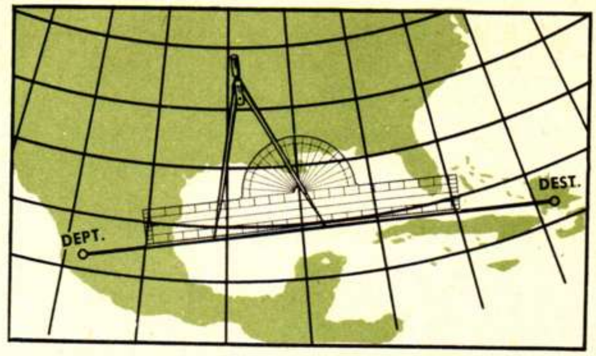
Find on the sectional map the mid-meridian intersecting this course line. Place the points of the dividers on the course line so that they are equally distant from the mid-meridian. Hold the dividers **perpendicular** to the map in order to avoid an error. With the plotter lying face up on the map, place the lower edge of the ruler portion against the dividers, along the course line. Slide the plotter along the course line until the **center hole** in the semicircular portion is directly over the mid-meridian.

To read your course, first note carefully the **direction** of the intended flight and be **sure** you select the correct scale on the semicircular portion of the plotter. If the destination point on the map is to the **right** of the point of departure, use the **outer** scale; if it is to the **left**, use the **inner** scale. Where the mid-meridian intersects the correct scale, read the course angle to the nearest one-half degree.

Always orient yourself on a map so that you have a rough idea of the course angle without even having to measure it. Visualize a compass rose graduated in each of the 360°. Divide this compass rose into four quadrants: 0° represents true north, 90° is east, 180° is south, and 270° is west.



Now visualize your intended course in terms of one of these quadrants. If your destination is northeast of your point of departure, the course angle is in the first quadrant, or somewhere between 0° and 90°, and is read on the outer scale. Similarly, if the destination is southwest of departure, the course angle is in the third quadrant, or somewhere between 180° and 270°, and is read on the inner scale of the semicircular portion of the plotter.



In determining the course angle, ALWAYS:

1. Lay the plotter on the map so that the semicircular portion is *above* the bottom edge of the ruler portion.
2. Place center hole over *the mid-meridian*. Don't try to place it over the course line.
3. Be sure you visualize clearly the *direction* of your intended flight before reading the course angle. Remember that if your destination is northeast or southeast of your point of departure, your course angle is between 0° and 180°, and you read it on the *outer* scale. If destination is northwest or southwest of the point of departure, your course angle is between 180° and 360° and you read it on the *inner* scale.

To Measure Distance

On sectional and regional maps, distance scales are printed on selected meridians and graduated in nautical miles. In order to measure the distance from departure to destination, first adjust your dividers to a convenient length on the distance scale. On a sectional map, 50 miles is a good unit to use. On a regional map, since the scale is smaller, it is more convenient to use 100 miles as your unit.

Holding the dividers lightly by the handle, place one pointer on the point of departure and the other on the course line. Then swing the dividers until the first point again touches the course line. In this manner continue to "walk" the dividers toward the destination.

Do this work very carefully, so that the dividers maintain the original spread. Keep strict account of the number of steps you "walk" the dividers.

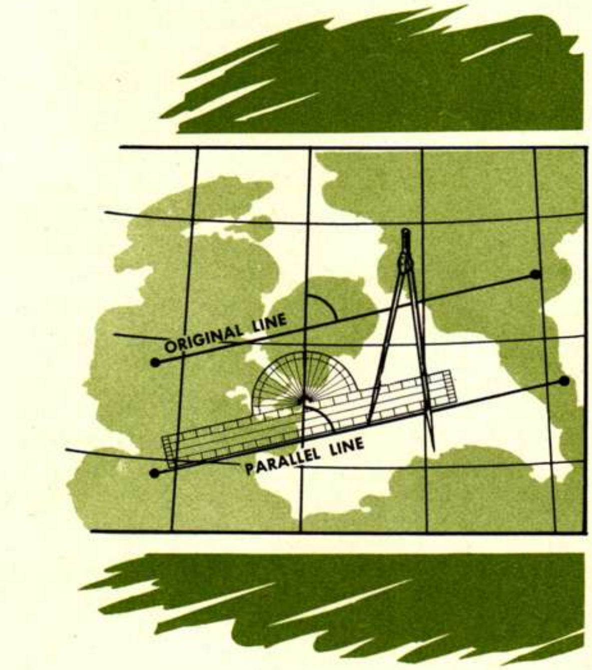
When you get so close to the destination that the next step will swing the dividers beyond the destination point, close the dividers in until the outer point touches the destination. Holding the dividers in this new position, set them on the scale and measure this short distance. Compute the total distance of the course by adding the segments you have measured.

For example, suppose that using a unit of 50 miles you make 5 complete steps and that your final short distance is 20 miles. The total distance from point of departure to destination is $5 \times 50 + 20$, or 270 nautical miles.

In measuring distance, ALWAYS

1. Hold the dividers lightly with one hand. Don't try to use both hands. Relax your grip before setting the dividers on the map.
2. Be sure to use the distance scale printed on a *meridian*. Don't try to use the scale on a parallel of latitude.
3. Count carefully the steps you "walk" the dividers.

HOW TO PARALLEL A LINE ON A PILOTAGE CHART



If you find yourself directly over a point several miles off course, you may need to know how to plot a parallel course. To do this, first locate on the map the point you are over. This is the point through which you draw the parallel course. Place one point of your dividers on this point and hold the dividers perpendicular.

Place the plotter face up on the map so that the edge of the ruler portion is flush against the point of the dividers. Holding the plotter against the point, manipulate it so that the center hole is exactly over the nearest meridian line. Find on the semicircular scale the angle that the original course line makes with that meridian, and manipulate the plotter until the meridian line passes through this angle on the scale. When the ruler edge of the plotter is on the point of the dividers, and the meridian passes through both the center hole and the desired angle on the scale, draw your parallel line along the edge of the ruler portion.

PILOTAGE PROCEDURE

Check Points

After you have plotted your course on the pilotage chart, look along the course line and pick out a number of **check points**. These are landmarks which you use to check your position from time to time during the flight. Good check points help you to stay on course. Furthermore, at each check point you figure the time you have flown and the distance you have traveled, and from this you compute your groundspeed.

Check points are all-important in pilotage. Select good ones and use them carefully.

A good check point, like a good reference point, must be prominent, distinctive, and unusual. If you select a small town as a check point, remember that small towns may look very much alike from the air. Therefore, select one which has other distinguishing landmarks near it, so that you can recognize it from the air by the pattern of the area.

Water landmarks usually make good check points. They have distinctive shapes, and are usually clearly visible. Buildings may have been moved or torn down since your map was made, but water features are not likely to be changed.

Highways, roads, railroads, cities, and towns make good check points. But to identify specific ones you must study the surrounding area.

If there are no outstanding landmarks along your course, you can use terrain features. Hills and valleys are hard to pick out, and can only be used to identify a general area. You can use as a check point some very outstanding feature, such as a lone peak.

Since you use check points for measurements of time and distance, do not select a large area. Instead, choose some relatively small feature within the area. For example, do not try to use a whole city as a check point. Select some outstanding feature in the city, such as a railroad yard or bridge.

Select check points that are **10 to 15 minutes apart** in flying time. This gives you enough time between check points to do your navigation work. If your check points are too far apart you can easily get lost. You may drift so far off course that you cannot see the next check point when you come opposite it. If they are too close together you cannot get an accurate groundspeed. Ten to 15 minutes is the best distance.

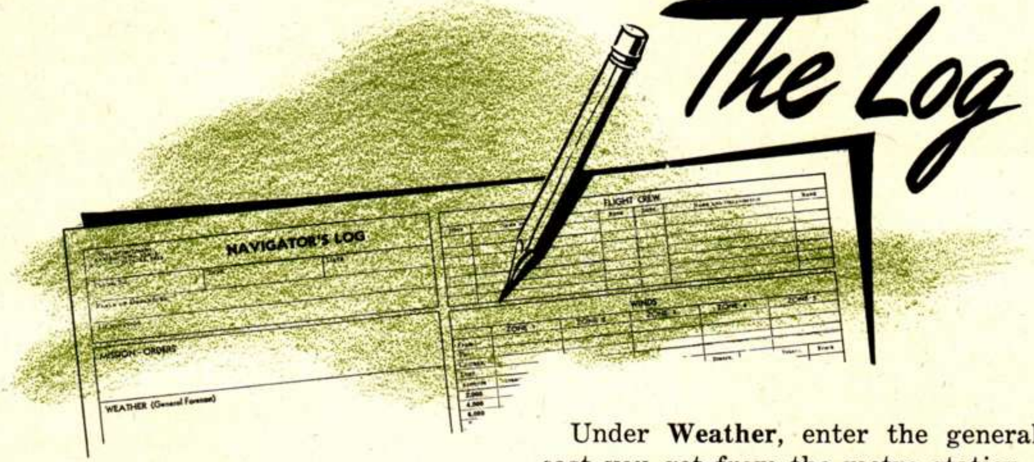
In addition to your principal check points, take note of all other landmarks along the course, and on either side of the course. Before your flight, fix clearly in your mind these landmarks you expect to see on your mission. When you are in the air, look for them, and use them to guide your airplane from one check point to the next.

Since you use check points to compute groundspeed, you must check carefully the exact time you pass over each one. To do this, you must sight all check points **along the same angle**. If you clock one check point when you sight it on the trailing edge of your wing, clock all of them on the trailing edge.

You cannot hope to sight all check points at exactly the same point on the airplane. One check point may be on the right side and the next one on the left. But you must clock all of them when you sight them at the same distance from nose to tail of the airplane.

PILOTAGE PROCEDURE

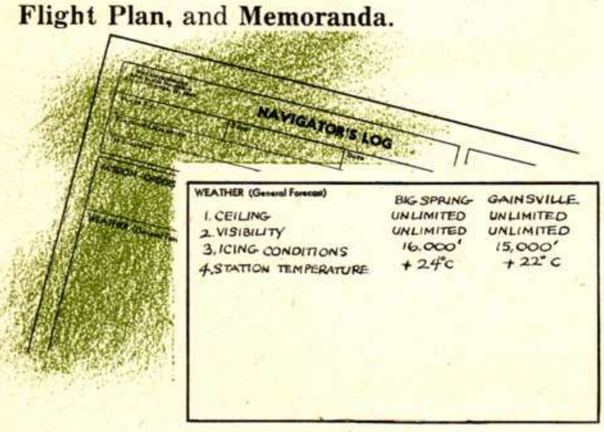
The Log



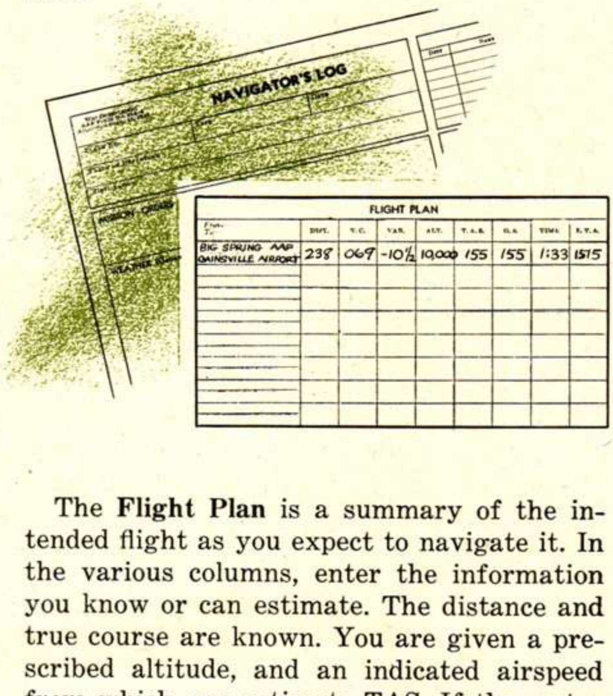
To navigate by pilotage successfully, you must keep a **log** of each mission. A log is a record of your flight. It is made on a specially prepared form called "Navigator's Log." On this form you enter before take-off various information which will help you to navigate the course. During your flight you enter additional information which enables you to stay on course and reach your destination at the prescribed time. After the flight is over, you complete the form and turn it in.

Learn and follow a definite order of procedure in filling out your log. Your time in the air is limited. But if you do each part of your work **when it should be done**, you have plenty of time to make all your calculations and enter your record in your log.

Before take-off, enter in your log the information you know. On the front page of the log, fill in the spaces labeled: **Plane No., Type, Date, Place of Departure, Destination, Flight Crew, Mission Orders, Weather, Winds, Flight Plan,** and **Memoranda.**



Under **Weather,** enter the general forecast you get from the metro station. Under **Winds,** enter whatever information the metro station can give you about the winds aloft.



The **Flight Plan** is a summary of the intended flight as you expect to navigate it. In the various columns, enter the information you know or can estimate. The distance and true course are known. You are given a prescribed altitude, and an indicated airspeed from which you estimate TAS. If the metro station gives you wind direction and force, use your E-6B to compute GS, and enter it in your log. Using GS and distance, find from your computer the **time** it will take to reach destination. Compute ETA and enter it. If you have no metro information, use TAS as GS and label it.

In the variation column, enter the compass variation you intend to use. On a short flight, use as your variation the average between variation at point of departure and variation at destination. On flights of more than 500 miles, you should plan your flight in segments, and enter a line of figures for each proposed segment.

Use the **Memoranda** space for any notes you wish to include, such as obstructions en route, auxiliary airfields, and alternate bases.

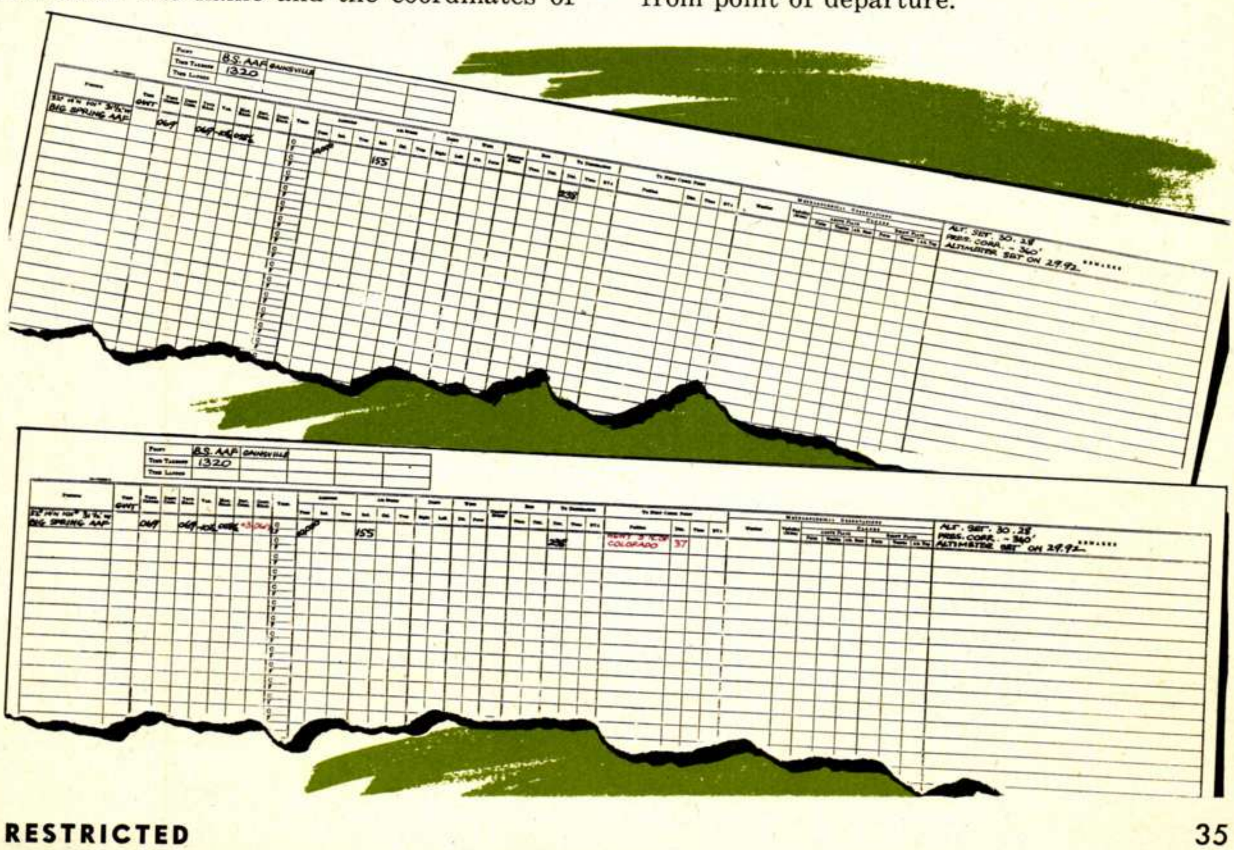
Next, under **Fuel Consumption** on the back of the log, enter the amount of gasoline in the tanks in the column marked **Total Gallons.**

On the work sheet inside the log, enter again the information you know. Under **Position** enter the name and the coordinates of the point of departure. In the box at the head of the **Time** column, enter the time zone of the point of departure. For example, if you are using Central War Time, enter "CWT." Leave the column underneath blank until you set course.

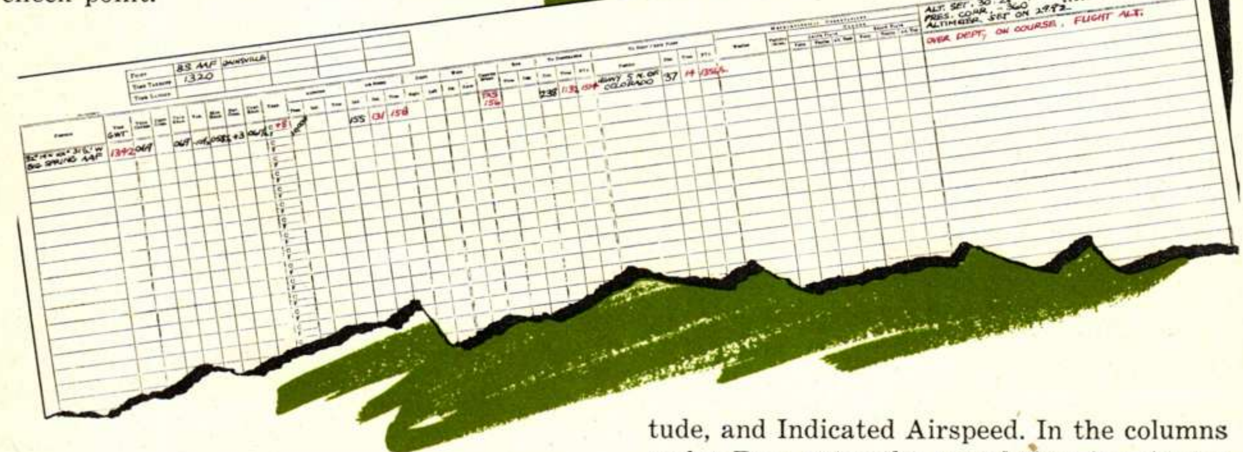
Fill in the first line of the **True Course, Variation,** and **Magnetic Heading** columns. If you have the necessary metro information compute the drift correction and the true heading. If not, leave the drift correction column blank, and enter true course as true heading.

The column labeled **Temp.** is for temperature readings at flight level. Leave it blank until you set course. From the information given in the briefing room, enter indicated altitude and indicated airspeed. From indicated altitude, you can compute calibrated and pressure altitude.

Before take-off, synchronize all clocks. Once in the airplane, read the compass deviation from the deviation card. Before reaching flight level, compute compass heading and enter it in your log. Also, in the column **To Next Check Point**, enter the name of the first check point you have selected and its distance from point of departure.



Give the pilot the **magnetic heading** before he is ready to set course. As soon as he is on course at flight level and over the point of departure, enter the time in the second column. Take a temperature reading, and enter the flight level temperature in the appropriate column. Read your airspeed indicator, convert to calibrated, compute your TAS, and enter it. With metro GS or TAS, and distance, compute the time it will take you to reach the first check point, and enter it. Take the time of departure (second column), add the time you have estimated to the first check point, and enter the ETA for the first check point.



In the first few minutes of flight, check all your instruments carefully.

About every five minutes during the flight, you should take instrument readings and enter time, compass heading, altitude, and indicated airspeed. If the temperature remains constant, put a check mark; if it has changed, enter the new reading. These 5-minute entries serve a double purpose. From them you can quickly notice any change in the data which you used to calculate ETA. Also, when you want to determine a pilotage wind, 5-minute entries give you more accurate average readings than 15-minute entries.

Watch the ground, and make note of your position with respect to the secondary check points you have selected. At least two minutes before you should be over your first check point, **start searching the ground for it. This is the most important single part of pilotage procedure.** DO NOT NEGLECT IT.

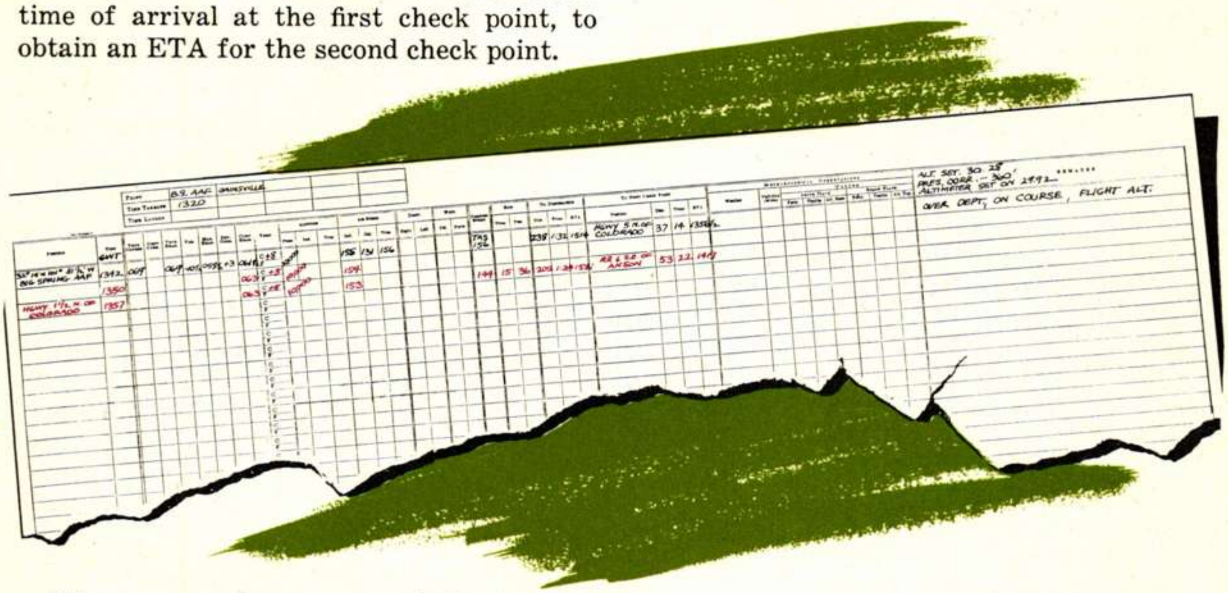
Remember that you selected principal check points 10 to 15 minutes apart. Do not waste time looking for one until you are near it. But give yourself at least two minutes to search before your ETA runs out, because if your GS is faster than your TAS you will be over your first check point sooner than you estimated, and may miss it.

When you are over the first check point, enter the correct information under Position, Time, Compass Heading, Temperature, Altitude, and Indicated Airspeed. In the columns under **Run**, enter the actual time in minutes between time of departure and exact time over the check point, and the distance flown. Set these two figures on your computer and read your GS.

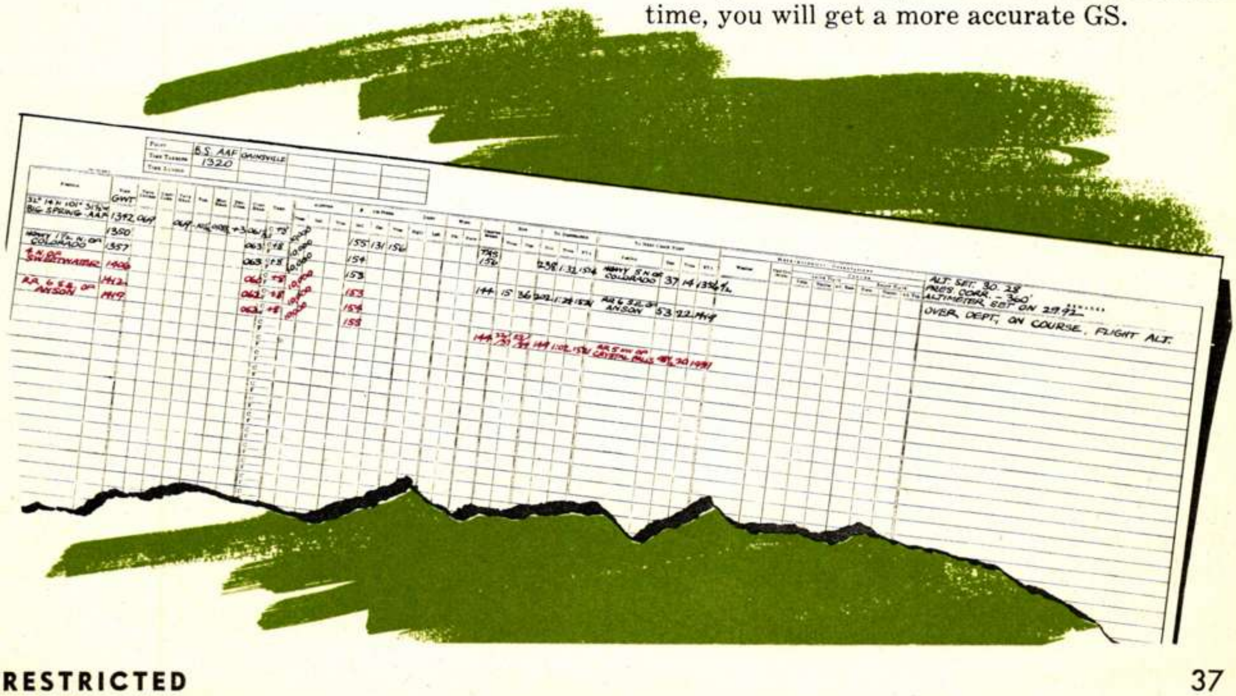
Notice that this is the actual GS for the first part of your flight. It may not be completely accurate because of the short distance flown, but it is more accurate than the metro GS or TAS you used to compute ETA for the first check point. Therefore, enter it under **Groundspeed**, and use it to compute a new ETA for destination.

To do this, first subtract distance already flown from total distance and enter the distance left to fly in the Distance column under **To Destination**. Set the new GS and this **remaining distance to be flown** on the computer, and read the time it will take to fly this remaining distance if your GS remains constant. Enter this time in the time column under **To Destination**. Add this time to the time over the first check point (second column) to obtain a new ETA for destination.

Under **To Next Check Point** enter the name of the second check point and its distance from the first check point. Using this distance and the new GS, compute the time it will take to reach the second check point, and enter. Then add this time in minutes to the time of arrival at the first check point, to obtain an ETA for the second check point.



When you reach your second check point, follow the same procedure, with one important exception. In the Time and Distance columns under **Run**, draw diagonals through the squares. In the upper part of the Time square, enter the time in minutes that you have flown from the first check point to the second. In the upper part of the Distance square, enter the distance between the first and second check points. In the **lower** portions of these squares, enter the **total** time and **total** distance from point of departure to the second check point. Use this **total** time and **total** distance to compute the new GS. Since you use a longer distance and period of time, you will get a more accurate GS.



As you arrive at each of the remaining check points, repeat this procedure. At each one, use the total time and distance from point of departure to **compute your GS.**

If your airplane stays on course, when you reach destination you **close out** the log. This means that you make a complete line of entries across the work sheet, filling in all columns that you used in your first line of entries, except **To Destination** and **To Next Check Point.**

Change of Course to Destination

If at any time during the flight you have to alter your course approximately 15° or more, you **double line** the log. This means that at the point where you change course, you make all entries as if you were closing out the log, and draw a double line across the work sheet under these entries.

Whenever you find yourself off course, you have to change your heading in order to arrive at your destination. To set up this new course correctly, you must determine the correct new compass heading.

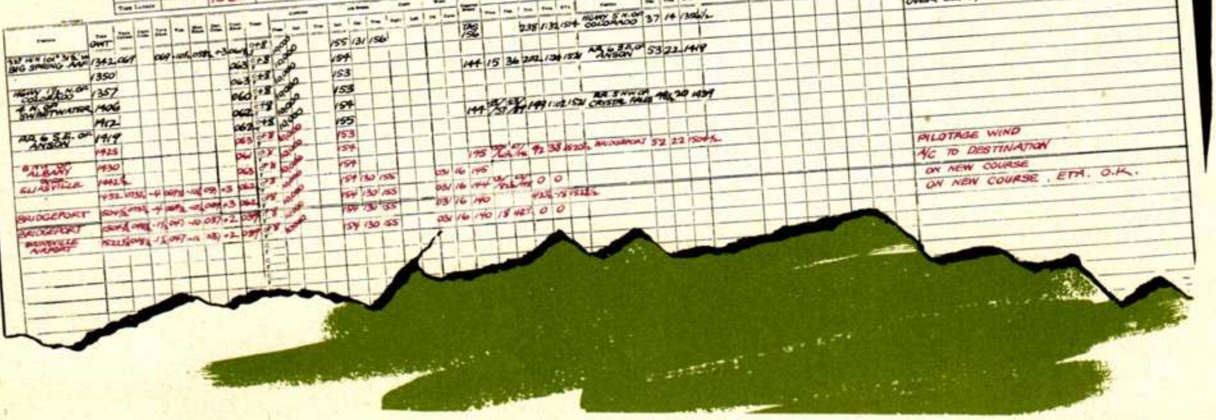
To do this, first draw a line on your map from the point you are over back to the point of departure. This line is your track, or the true course you have made good. Extend this track line to some point you can use as a **turning point.** This turning point should be a clearly recognizable landmark, and it should be four or five minutes ahead of you.

Draw a line from the turning point to your destination. This line is the true course you want to make good on the new heading. With the plotter and the dividers, determine the angle between this line and the meridian. When you apply deviation, variation, and drift on the new heading to this angle you can obtain your new compass heading.

In order to find the drift on the new course accurately, you must determine at this point the direction and speed of the wind. You also need this **pilotage wind** to compute an accurate groundspeed for the remainder of the flight and to predict an accurate ETA. Remember that you can get a wind from your computers if you know true heading, drift, true airspeed, and groundspeed. You have in your log this information for the part of the flight you have already completed.

For finding your true heading, you have on your log a column showing the compass headings every five minutes along the course. Take the **average** compass heading, and by applying the correct deviation and variation find the **average true heading.**

Drift is the difference between the average true heading and the true course you have made good up to the point where you change



course. Determine the track with your plotter, and compute the difference.

You get your **average true airspeed** by taking first an average of your indicated airspeeds and converting it to an average calibrated airspeed. Using average temperature, average pressure altitude, and average calibrated airspeed, find from your E-6B computer the average true airspeed.

Your **average groundspeed** is the last groundspeed you computed and entered in the log, since it was figured for the whole flight from the point of departure to the point where you change course.

Now set up on your computer the average true heading, drift, average TAS, and average GS, and read the wind. Enter the direction and force of this wind in the Wind column on the double line. Also on this line in the **Remarks** column, write "Pilotage Wind."

On the next line of the log, fill in the new information, applying the wind to the new true course to find the new compass heading. Also use the wind to compute a new GS, so that you can compute a new ETA accurately. On this line be sure that you put an entry in each column you used in the first line of the log. Continue filling in the log in the usual manner until you reach destination. At that point, close out your log.

NOTE:

Deviation usually changes when you change course. Before you figure your new compass heading, ALWAYS read your deviation card again, and note the deviation on the new magnetic heading.

The **distance** from turning point to destination is **longer** than the difference between distance traveled and original total distance from departure to destination. Therefore, ALWAYS measure this new distance with your dividers.

POINTS TO REMEMBER IN KEEPING LOGS!

1. In keeping your log, remember to fill out *completely* the first line, the last line, and the lines immediately above and below any double line indicating a change of course. At approximately 5-minute intervals, enter time, compass heading, temperature, altitude, and indicated airspeed, whether you are over a check point or not. Over each check point, put in this same information and in addition, fill in all columns under *Groundspeed, Run, To Destination,* and *To Next Check Point*.

2. In the *Position* column, enter the name and the coordinates of point of departure and destination. For positions of check points, enter the name if you know it; if you do not, enter the coordinates.

3. In recording time, use the 24-hour clock system. That is, for 1:23 P. M. write 1323.

4. Use 3-figure groups for all entries of course and heading. If your course is 7°, enter 007; for a heading of 39°, enter 039.

5. Remember that your instruments are extremely sensitive, and record the slightest changes in altitude, airspeed, and heading. The pointers jiggle and swing constantly in flight. Therefore, keep your eye on your instrument, and when you take a reading take the average position of the pointer for a period of approximately 5 minutes.

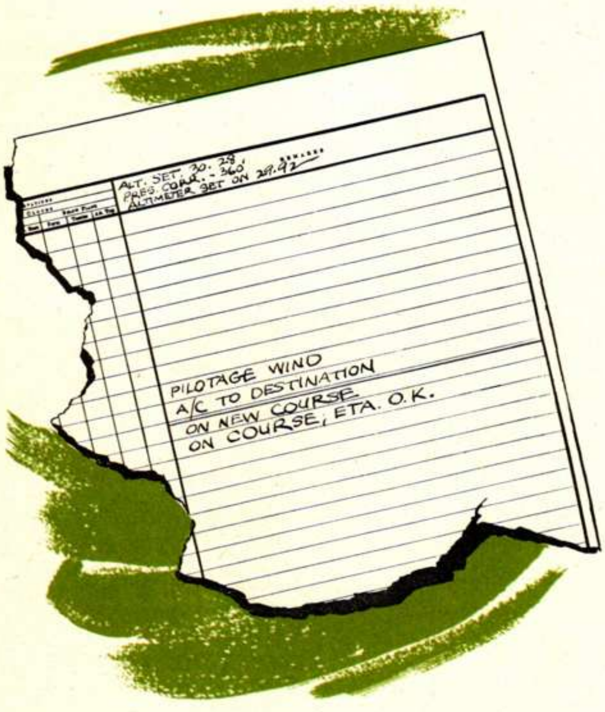
6. In computing groundspeeds after the second check point, ALWAYS use *total time* and *total distance from point of departure*.

7. In clocking check points, ALWAYS use the same angle of sight.

Drift, Metro, and Remarks Columns

In navigating by pilotage you do not need to make any entries in the column headed **Drift**. This column is used only to record drift on the right and left legs of a double drift when navigating by dead reckoning.

Also, you can disregard the column headed **Meteorological Observations**. It is included on the log because sometimes flights are made over areas about which the metro station has no information. A record of the navigator's observations on such a flight is of value to the metro station at the destination point.



The **Remarks** column, on the other hand, is useful to you and you should use it. Notes entered here help to give you a complete record of your flight. Use this column to record all important information for which there is no other space provided on the work sheet. Also, if anything unusual happens during the flight, enter a note of it under **Remarks**.

Here are some typical entries you might make in the **Remarks** column:

1. Altimeter setting 30.02.
2. Engines started 1427.
3. Departed on course at flight level.
4. Three miles left of San Antonio (check point).
5. Pilotage wind.
6. Altered course.
7. Right engine sputtering.
8. Snow flurries.
9. Gas getting low. Only 42 minutes flying time left.
10. Over destination. ETA 1 minute late.

SPECIAL POINTS IN PILOTAGE

Methods of Determining a Pilotage Wind

Whenever you drift off course, you can determine the pilotage wind by using true heading, drift, TAS, and GS. This is called the **groundspeed and drift method.**

There are three other methods. Each one is useful under a different set of circumstances, because each depends on the use of different known factors. Master all four methods. When on a mission you need to determine a pilotage wind, use your head in selecting the proper method. This depends on what information you have. Use the method that calls for that information.

1. **Pilotage Wind from Groundspeed on Three Headings.**

When you fly three legs of a mission on three different headings, you can use the groundspeed on each of the three headings to determine the direction and force of the wind. To use this method you must know your three groundspeeds, your three compass headings, deviation on each heading, average variation, and true airspeed. With this information, you can determine the wind by using the E-6B computer.

If you have flown on only two legs, you can get a pilotage wind by this method. With only two groundspeeds on two headings, however, you do not get as accurate a wind.

2. **Pilotage Wind from Drift on Two Headings.**

When you have flown two legs of a mission on two different headings, you can determine a pilotage wind by using the drift on each heading. To use this method, you must know the two drifts, the two compass headings, deviation on each heading, variation, and true airspeed. To find the drift, you must know the true course you have made good on each leg. This true course made good is called the track.

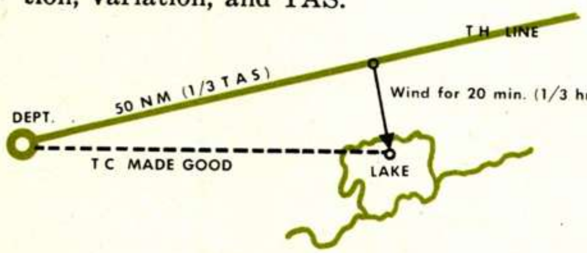
You cannot use this method successfully unless you can determine accurately the track made good on each leg. To do this, mark the last recognized landmark you flew over on the first leg. Draw a line from it back to the point of departure. Then, using the plotter and the dividers, determine the course angle of this line. In the same manner, determine the track of the second leg.

Suppose your average variation is 16° E and you have maintained a constant TAS of 180 k on both legs. On the first leg, your compass heading was 160°, deviation 0°. The true heading on this leg was therefore 176°. You have found that the track on this leg was 181°. The difference between track and true heading is –5°. This means that you had 5° of right drift.

When you have obtained all the necessary information, set it on the computer and solve for wind.

3. **Pilotage Wind from Airplot**

At any point on a flight you can determine a pilotage wind by the airplot method if you know your position with reference to a landmark on the earth. The airplot method is simple, but requires very careful plotting on the sectional or regional chart. You do not use your computer in this method. To use this method you must know the location of your landmark, the time you have flown from point of departure, compass heading, deviation, variation, and TAS.



Suppose that after you have flown 20 minutes from point of departure on a compass heading of 78°, you find yourself over a small lake which you recognize. Locate this lake on the map.

Now determine your true heading. If your deviation is –2° and variation is 6° W, the true heading is 74°. Using the dividers and the plotter, draw a line from point of departure in the direction of 74°.

Compute your TAS and measure on this true heading line the distance you would fly at that TAS in the time you have actually flown. For example, if your TAS is 150 k, and you have been flying 20 minutes, the distance is 50 nautical miles. Measure this distance on the true heading line, and mark the point.

Now draw a line from this point to the lake you are using as a landmark. The angle between this line and a meridian is the **direction** from which the wind is blowing. Remember that the wind blows **from** true heading **to** true course. The length of this is the **force** of the wind. If this line is 3 nautical miles long, and you have been flying 20 minutes when you make your airplot, the wind has blown 3 nautical miles in one-third of an hour. Therefore, the force of the wind is 9 knots.

Pilotage Deviation

The deviation of the compass in an airplane is an important factor in many pilotage problems. Normally you find in each airplane a deviation card, which gives the correct deviation for various headings. If you should lose this card, or if it should be incorrect, you must know how to determine the deviation by pilotage methods. You can do it if you know the drift on a given heading.

Apply the drift correction to the true course you have made good to obtain true heading. Then apply variation to true heading to obtain magnetic heading. You know that deviation is the difference between magnetic heading and compass heading. Since you have the compass headings at various points of the flight recorded in your log, take an average of these readings as the average compass heading. Then the difference between this average compass heading and the magnetic heading is the correct deviation.

Off-Course Corrections

Whenever you are off course and have to correct in to destination you can determine the correct new compass heading by plotting in the new course line and applying drift, variation, and deviation. This method is accurate, but it is slow. Here are two quick methods for correcting in to destination. Both are sufficiently accurate and easy to use.

To use either of these two methods, you must know three distances. These are: (1) **distance run** from point of departure to turning point; (2) **distance to run** from turning point to destination; (3) **distance off course**. Measure distance run and distance to run with the dividers, using the scale printed on a meridian. Draw a line from turning point **perpendicular** to the line of your original intended course. This line is distance off course. Measure it with the dividers.

The first method for determining the correction to make in compass heading in order to correct in to destination is worked out on the E-6B computer. Here is the method:

1. Put the square grid portion of the card under the transparent face. Mark with a dot the correct **distance off course**. If you are right of the intended course, place the dot to the right of the center line. If you are off left, put it to the left.

2. **Without moving the compass rose,** reverse the card, and put **distance run** under the grommet. Make a note of the number of degrees right or left indicated by the dot.

3. Slide the card up or down until **distance to run** is under the grommet. Make a note of the number of degrees indicated by the dot.

4. Add the two numbers of degrees. The sum is the necessary correction you must make in compass heading. If you are right of course, tell the pilot to turn this total number of degrees to the left.

Actually, this method gives you a course correction and not a compass correction, but for all practical purposes it can be used as a compass correction.

The second method for finding off-course correction is even quicker. You get your correction in degrees by solving two equations and adding the results.

1. $$\frac{\text{Distance Off Course}}{\text{Distance Run}} = \frac{X^\circ_1}{60}$$

2. $$\frac{\text{Distance Off Course}}{\text{Distance to Run}} = \frac{X^\circ_2}{60}$$

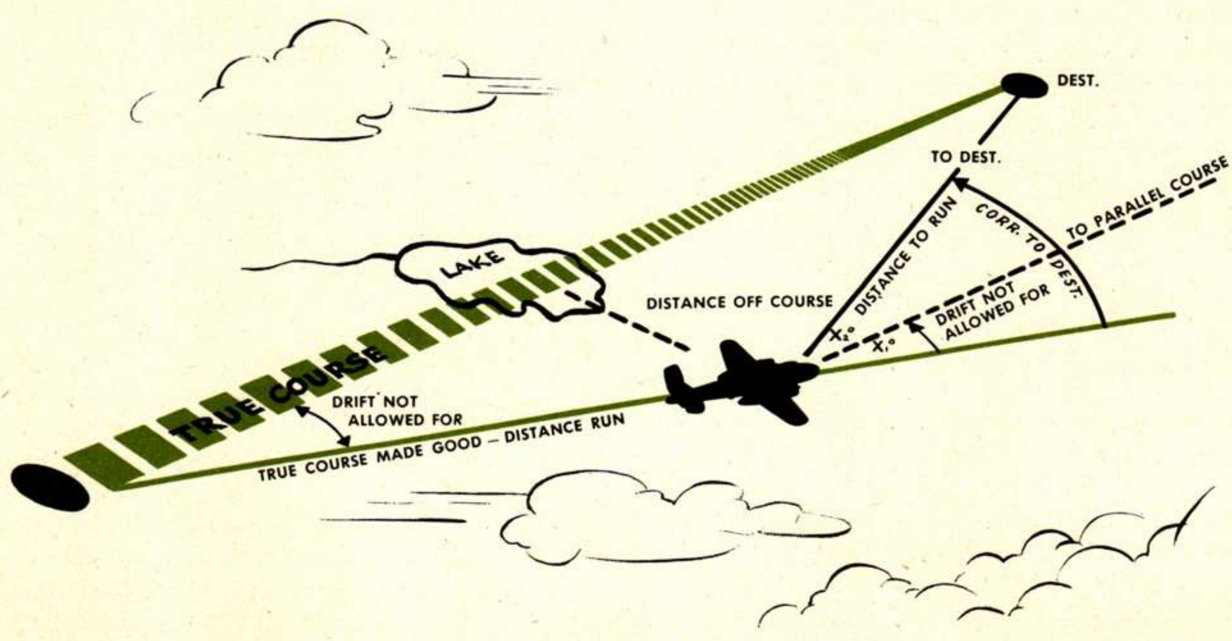
3. Sum of the two unknowns $(X^\circ_1 + X^\circ_2)$ is the total number of degrees to correct.

You can solve the two equations either on the slide rule face of the computer or by working them out on paper.

Climb on Course

In all your early navigation missions, the pilot climbs to flight level before setting course to destination. You start your log when you are on course directly over point of departure at flight level.

Later on, and in all practical missions, there is no need to waste time circling the field as the airplane climbs to flight level. Instead, the pilot sets course as soon as he has cleared the traffic pattern, and **climbs on course.**



When this happens, you begin your log in the usual manner. When you reach flight level and level off, pin-point your position, and use this point as the new point of departure. When the airplane begins straight and level flight, the indicated airspeed will be greater than it was during the climb. Therefore you must use the pin-point position as the point of departure in order to compute an accurate groundspeed.

Night Pilotage

Offhand, you might think that night pilotage is more difficult than day pilotage because at night you can see fewer objects on the ground. Actually, it is easier to navigate by pilotage at night than by day.

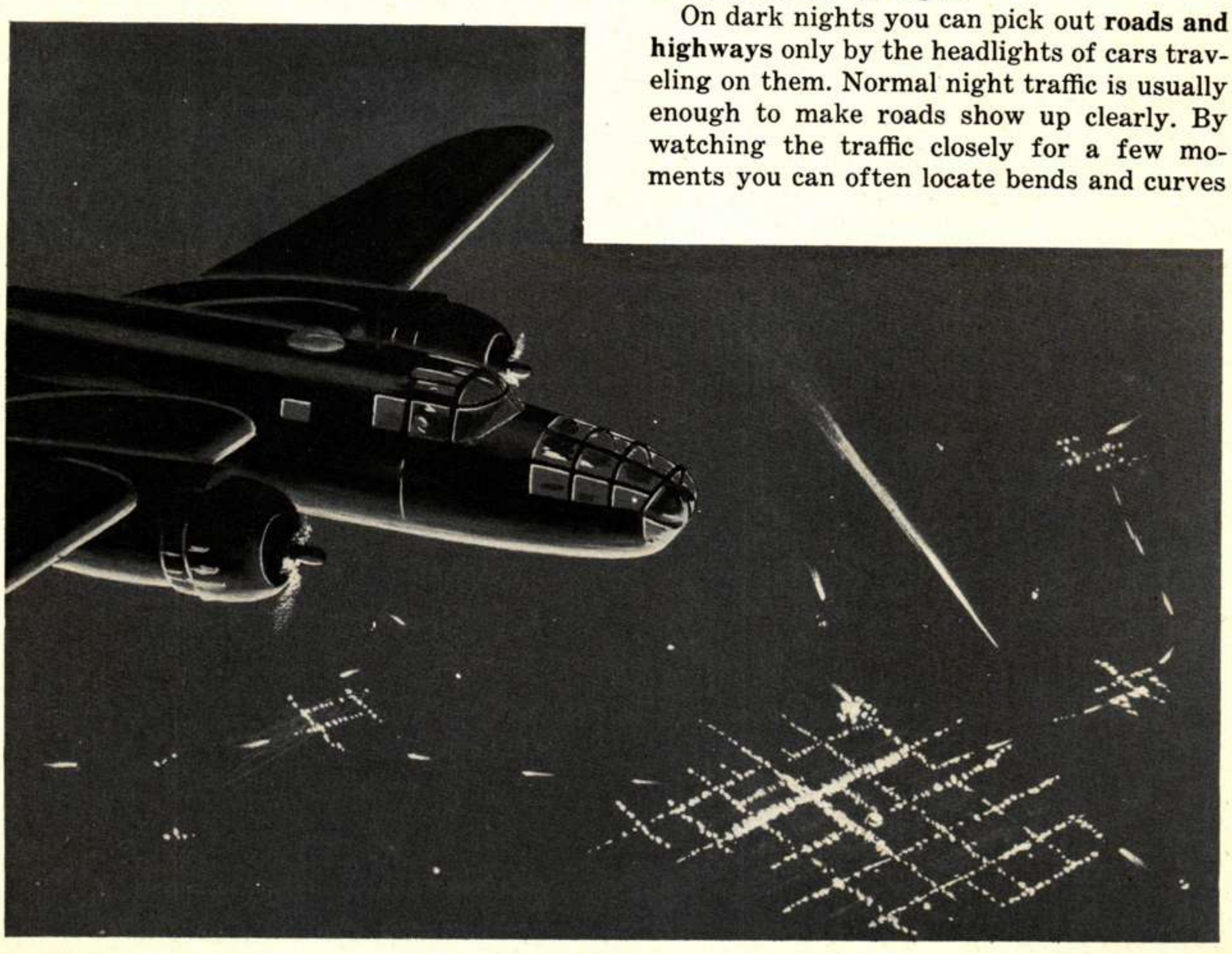
There are several reasons for this. In the first place, since you can see fewer objects it is easier to concentrate on those you can see. Also, certain features show up more clearly by night than by day.

On a clear night when there is bright moonlight, you can see very much the same as in daylight. But even on dark, overcast nights, many features stand out clearly.

Water features are very easy to identify. On clear nights, even when there is no moon, the surface of water reflects enough light to make it show up clearly. If flying in combat territory, remember that water is the hardest feature to conceal by blackouts.

Unless the area is blacked out, the lights make **towns and cities** show up more clearly and from greater distances than in daylight. Furthermore, it is much easier to distinguish one city from another, because the shape of the city as formed by the lights corresponds very closely to the shape of the city as it is shown on your pilotage chart. Since you can pick up lights from great distances, it is easier to identify small towns by noting their relation to other small towns. In other words, the pattern formed by a group of small towns is much clearer at night.

On dark nights you can pick out **roads and highways** only by the headlights of cars traveling on them. Normal night traffic is usually enough to make roads show up clearly. By watching the traffic closely for a few moments you can often locate bends and curves



in the road. If you intend to fly over a blacked out area, however, do not plan to use as a check point any feature identified by lights.

Air fields show up well at night. All of them have beacons and most of them have runway lights. The more important air fields can often be identified by the runway lights and lighted buildings.

Light lines are of the utmost value in night pilotage. A light line is a series of beacons at intervals along a much-traveled airway. The individual beacons in light lines are shown on all pilotage charts. Therefore light lines make excellent check points for night pilotage. Many individual beacons identify themselves by flashing a visual code letter. The pilotage chart shows the identifying code for each of these beacons.

Line of Position and Fix

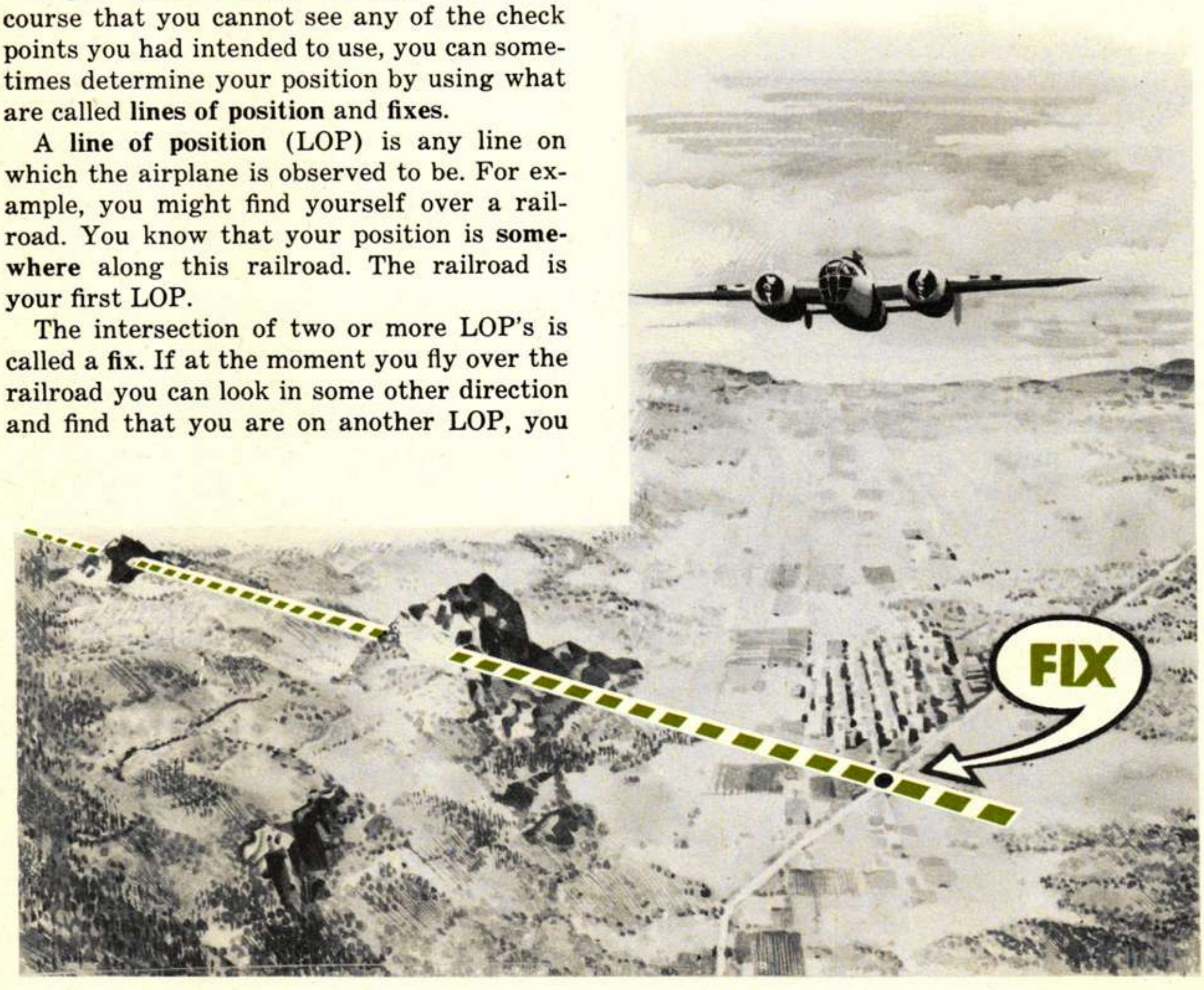
If you should at any time get so far off course that you cannot see any of the check points you had intended to use, you can sometimes determine your position by using what are called **lines of position** and **fixes**.

A **line of position** (LOP) is any line on which the airplane is observed to be. For example, you might find yourself over a railroad. You know that your position is **somewhere** along this railroad. The railroad is your first LOP.

The intersection of two or more LOP's is called a **fix**. If at the moment you fly over the railroad you can look in some other direction and find that you are on another LOP, you know that you are on the **fix** of those two LOP's. For example, if you look off to the side and discover two objects exactly in line, then a line drawn through those two objects is an LOP, and you know that the airplane is somewhere along this line. Obviously, in this example, the airplane is at the intersection of the two LOP's.

Note the time of the fix, and plot it on your map after locating the railroad and the two objects. The coordinates of the fix give you your position.

In determining a fix, remember that you must use as LOP's either clearly visible straight lines on the ground or an imaginary line through at least **two** objects besides the airplane.



USE YOUR HEAD

You can learn navigation thoroughly only by navigating. It is possible to learn all the procedures for pilotage, and still not be able to guide an airplane from one point to another. You cannot get by with learning theory. You must cultivate your senses. You must keep wide awake. You must practice navigation every minute of every mission.

All problems in navigation are problems of direction and distance. In addition to knowing how to solve these problems, cultivate in yourself a **sense of direction** and a **sense of distance** in relation to time.

Before you start out on a mission, **fix** in your mind a clear conception of the general direction of your intended flight. As you do your work in the air, remember that all headings are bound to lie somewhere in this general direction.

Would-be navigators often compute a heading exactly opposite to the intended heading because they do not keep the general direction of flight in their minds. Avoid this common error by training yourself to think of course ALWAYS in terms of direction **from** departure **to** destination.

In addition to visualizing the general direction of a flight, make it a habit to form a clear mental picture of the course you intend to fly. Using your chart, study the pattern of your various check points. Fix this pattern in your mind in terms of right and left. Note which check points should appear on your right hand if you are on course and headed in the proper direction.

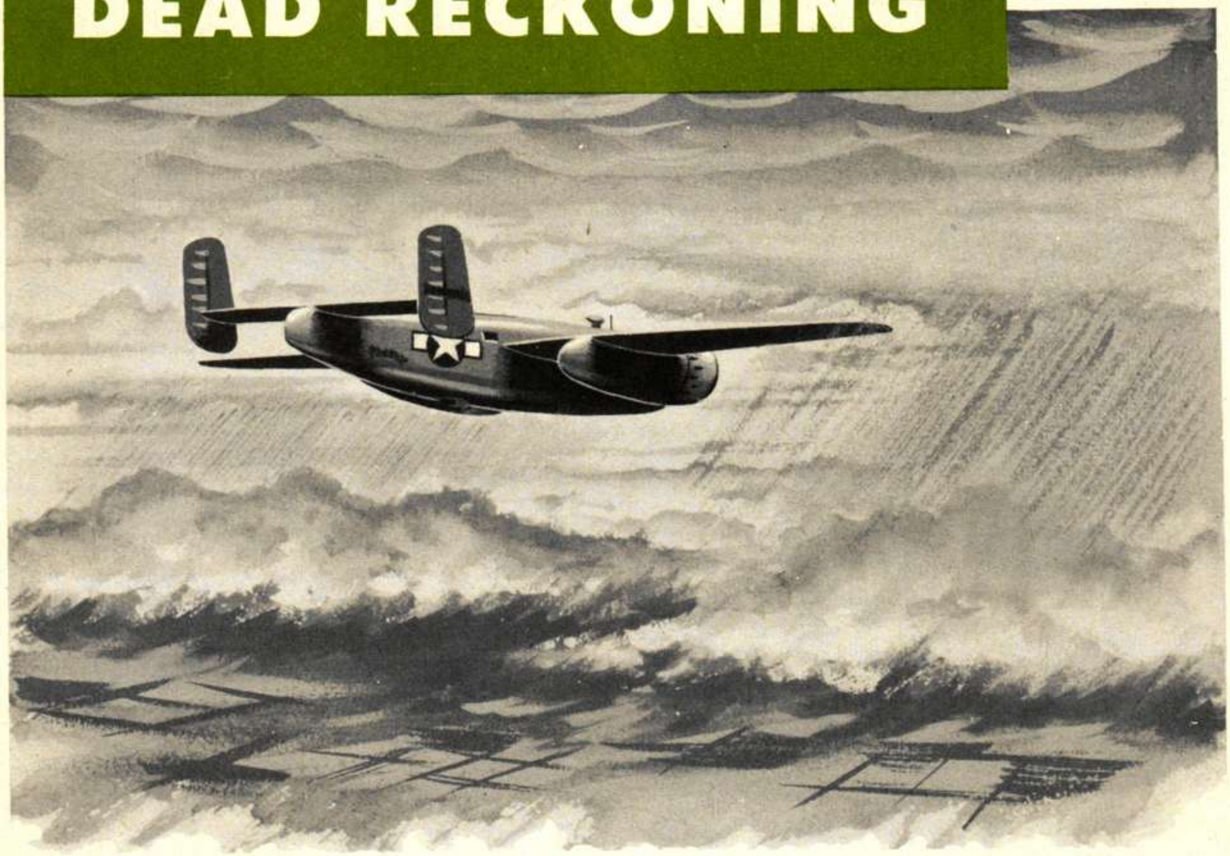
In the early stages of your training, give yourself problems that will help to train your sense of direction. Before you take off, plan how you would solve imaginary problems that might arise on the mission. For example, select a check point that is slightly left of the intended course. Then think out what you should do if in the flight this check point appears on your right. Realize that if this should happen you would be off course to the **left**, and that you would have to make a correction to the right to get back on course.

Try to develop also a sense of the relations of time, speed, and distance. For example, if you are making a GS of 180 mph, you know that in 20 minutes you will fly 60 miles over the earth. Think out what part of the course you should be over at the end of the 20 minutes, and try to visualize the check points which should be visible at that time. As you approach the end of the 20 minutes, concentrate on that part of the course as you have visualized it in your mind.

In working any problem involving wind, try to **visualize** the speed and direction of the wind in addition to computing it. If your GS is slower than your TAS, you know the wind must be from some direction ahead of the lateral axis of your airplane. A wind from any direction behind this lateral axis would make your GS faster than your TAS. Similarly, if you are drifting off course to the right, you know the wind must be from some direction left of the longitudinal axis of the airplane, and **vice versa**. Use this common sense knowledge as a check on your computations.

Remember that in all navigation you use the 24-hour system of time. Practice using it until you automatically think of time in this system. Use it for all your time-keeping on the ground. Do not make the common error of referring to 3:00 P. M. as 1300. Practice using the 24-hour system until you automatically add 12 to any PM hour.

DEAD RECKONING



INSTRUMENTS:

The Mercator Chart

Dead reckoning (DR) is a method of navigating by the use of instruments and computations, without the aid of visible landmarks. It is the basic method of all navigation.

The great importance of DR is that its use is less limited than that of any other method of navigation. It is often possible to navigate by DR when it is not possible to use any other method. Furthermore, you generally use DR in conjunction with other methods.

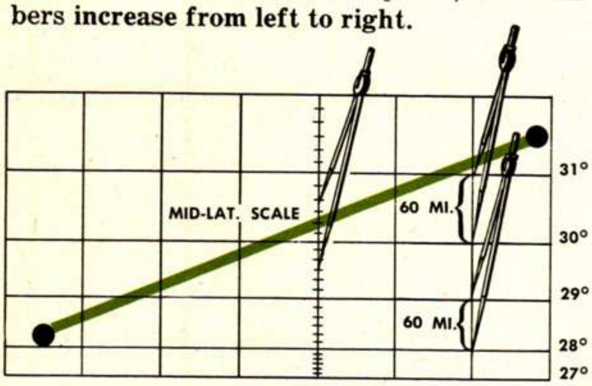
Successful DR has two absolute requirements. First, you must **read your instruments accurately**. Second, you must **determine the correct wind**. All your computations depend on one or both of these factors.

The instruments you use in DR are the airspeed indicator, altimeter, compass, free air temperature gage, watch, and drift meter. The drift meter measures the drift and shows you what drift correction to make. In addition to these flight instruments, you use the plotter and dividers for your plotting and the E-6B computer for your calculations.

To solve your plotting problems, you use the Mercator plotting chart. On this chart it

is very easy to measure course angles, since any straight line intersects all meridians at the same angle. You can measure a course angle at **any** meridian. It is also easy to plot positions when you know their coordinates.

The Mercator plotting charts you use are not complete maps. They have nothing on them except lines indicating parallels and meridians. The parallels are numbered, but the meridians are not. You must write in the correct numbers of the meridians for the area you intend to fly over. This makes it possible for you to use the chart for any area of the earth's surface lying within the latitude boundaries. If the area you intend to fly over lies in the **western** hemisphere, the meridian numbers **increase from right to left.** If it is in the **eastern** hemisphere, the numbers **increase from left to right.**



Latitude scales are printed on certain meridians, and longitude scales on certain parallels. You use these scales in locating points by coordinates. Also, you use the **latitude scale** for measurements of distance, since one minute of latitude is equal to one nautical mile.

In measuring distance, remember that on a chart made from the Mercator projection the latitude scale is not constant. Therefore, always use the **mid-latitude scale.** This is the section of the latitude scale which lies midway between the latitudes of the two points.

The north-south width of a Mercator plotting chart is usually not more than 11°. For example, the outside parallels shown may be 27° N and 38° N. You can use such a chart for any area lying between these two parallels. Also, if you reverse the chart so that the larger parallel is at the bottom, you can use it for any part of the area lying between the same parallels in the southern hemisphere.

VECTORS IN DEAD RECKONING

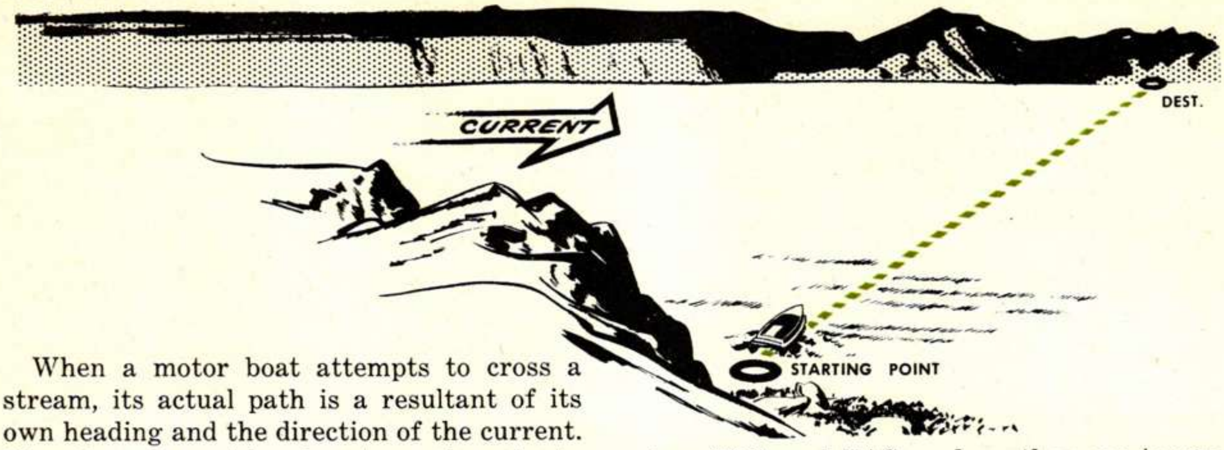
The central problem in dead reckoning is the problem of determining the effect of the wind on the path of an airplane, without reference to checkpoints on the ground. If you could fly through still air, you could simply head the airplane in the direction of the desired course and it would arrive at its destination. Also, your GS would be the same as your TAS, and you could predict your ETA by simply dividing the distance to fly by TAS.

But since you are flying through air which is **moving,** the movement of the air **changes the path** over the ground and also **changes the speed** at which the airplane passes over the ground.

When the air is moving in exactly the same direction as the airplane (tailwind) or in exactly the opposite direction (headwind), it does not change the path of the airplane over the ground. The only thing it changes is the GS. For example, if you are flying at a TAS of 150 knots directly into a wind of 10 knots, you actually travel over the ground at a speed of 140 knots. Similarly, if you fly a TAS of 150 knots in air which is moving 10 knots in the same direction, your GS is 160 knots.

Whenever the wind blows from any direction other than dead ahead or dead astern, it also changes the path of the airplane over the ground. The airplane is affected by **two forces** moving in **two directions.** The engines carry it forward at its TAS in the direction of its true heading. At the same time, the air moves at the speed of the wind from a given wind direction.

The result of these two motions is a third motion, which is the actual path and speed of the airplane over the ground. The direction of this actual path, or **true course made good,** is a **resultant** of the true heading and the direction from which the wind blows. The GS is the resultant of TAS and the speed of the wind.

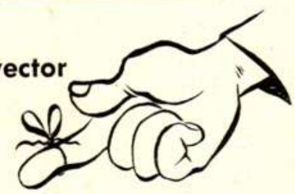


When a motor boat attempts to cross a stream, its actual path is a resultant of its own heading and the direction of the current. Therefore, it must head upstream in order to reach a point directly across the stream. In the same way, an airplane must head upwind in order to make good a desired path over the ground. The basic problem in DR is to head the airplane correctly so as to counteract the effect of the wind. In other words, you must crab the airplane into the wind, so that the resultant between wind and true heading will lie along the true course you wish to make good.

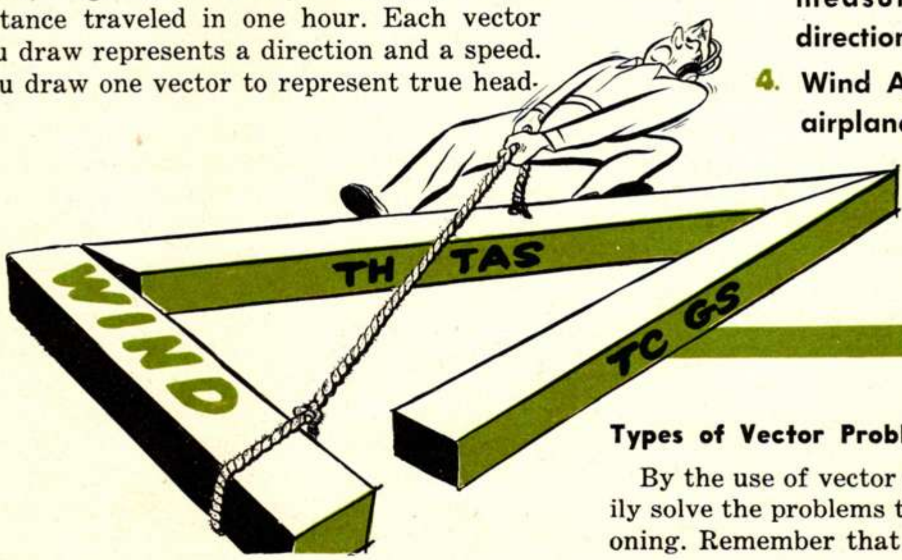
To understand this problem visually, you must be able to construct a graphic representation of it on your plotting chart. You do this by making **vector diagrams**. Use the Mercator plotting chart for all vector diagrams, because it has a scale for measuring distances and north-south meridians for plotting direction angles.

A **vector** is a straight line representing both **direction** and **magnitude**. For your purposes, magnitude is always rate, that is, the distance traveled in one hour. Each vector you draw represents a direction and a speed. You draw one vector to represent true heading (TH) and TAS, and another one to represent wind direction and wind speed. The resultant of these two vectors is a third vector which represents the true course made good (TC) and the GS. These three vectors form the **vector triangle.**

When you construct vector diagrams, remember these four simple facts:



1. **GS is ALWAYS measured along TC.**
2. **TAS is ALWAYS measured along TH.**
3. **Wind speed is ALWAYS measured along wind direction.**
4. **Wind ALWAYS blows the airplane from TH to TC.**



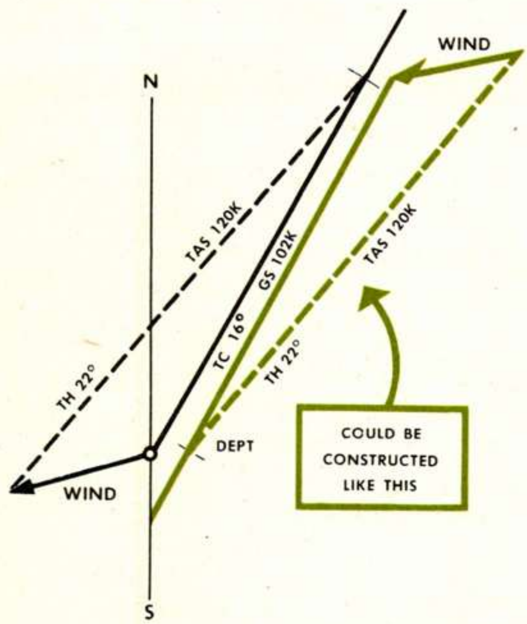
Types of Vector Problems

By the use of vector diagrams you can easily solve the problems that arise in dead reckoning. Remember that a vector triangle represents six factors — three directions and three speeds. When you know any four of these six factors, you can construct the vector triangle. Then by measuring the vectors you can determine the two unknown factors. Here are the four types of problems you solve in dead reckoning.

①

GIVEN: TC to be made good.............16°
TAS ....120 k.
Wind ....54°/21 k.

TO FIND: TH and GS.



Solution

1. Select any point to represent point of departure. From this point draw the TC. Make this line slightly longer than the given TAS.

2. From the point of departure, draw in the wind arrow **from** 54°. Make the length of this wind arrow 21 knots, or 21 nautical miles on the mid-latitude scale.

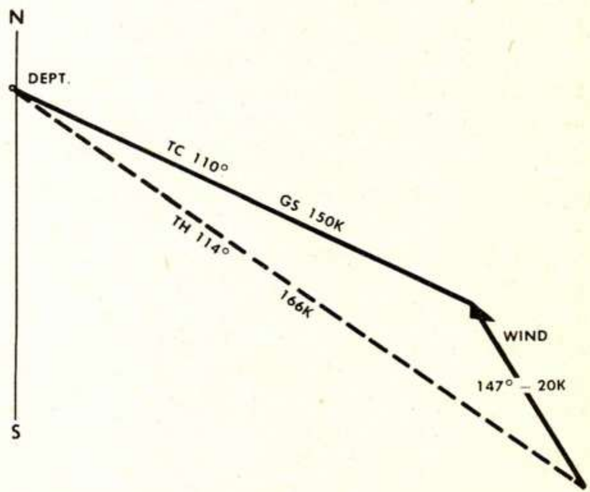
3. Extend the dividers to TAS distance. With one point on the point of the wind arrow, swing the dividers across the TC. Draw a broken line from the point of the wind arrow to the point where the dividers intersect the TC. The length of this broken line represents TAS (120 k.), and the angle it makes with true north is the TH (22°).

4. GS is the length of the TC line from point of departure to the point where the TAS intersects the TC. Measure this distance representing GS, 102 k., with your dividers.

②

GIVEN: TC ....110°
GS ....150 k.
TH ....114°
TAS ....166 k.

TO FIND: WIND DIRECTION AND SPEED



Solution

1. Select any point to represent point of departure. From this point draw the TC. Make the length of this line equal to the GS, 150 k.

2. From the point of departure, draw the TH. Make the length of this vector equal to the TAS, 166 k.

3. Connect the ends of these two vectors with a straight line. This straight line is the wind vector. Remember that the wind blows the airplane **from** TH **to** TC. Therefore the point of the wind arrow is on the TC line.

4. The angle which this wind vector makes with true north is the **direction** from which the wind is blowing, 147°. The length of this wind vector is the **speed** of the wind, 20 k.

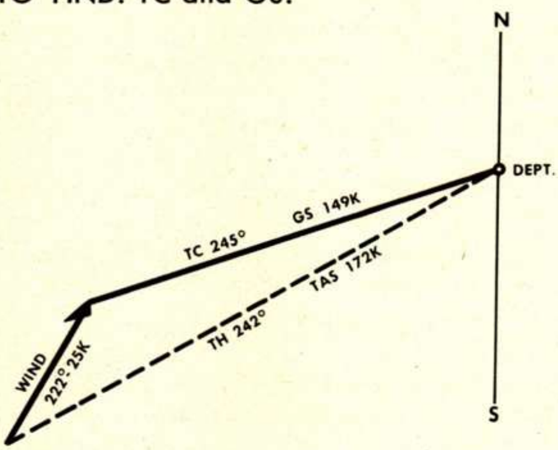
3

GIVEN: Wind direction and speed ....222°/25 k.

TH ....242°

TAS ....172 k.

TO FIND: TC and GS.



Solution

1. Select any point to represent point of departure. From this point draw the TH. Make the length of this line equal to the TAS, 172 k.

2. From the end of this TH vector, plot the wind arrow from 222°. Remember that wind blows the airplane from TH to TC, and that the point of the wind arrow points in the direction opposite to 222°. Make the length of this wind arrow equal to the speed of the wind, 25 k.

3. Connect the point of the wind arrow and the point of departure with a straight line. The angle this line forms with true north is the TC, 245°. The length of this line is the GS, 149 k.

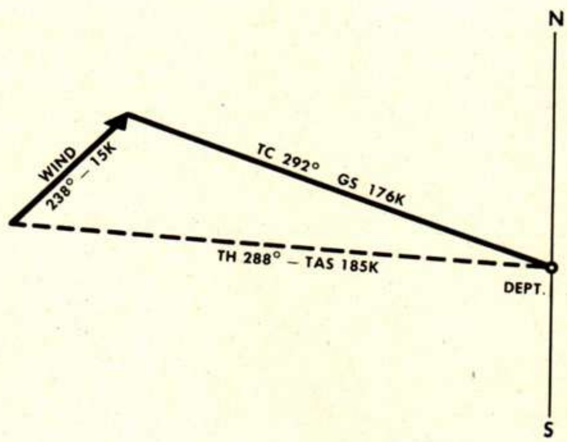
4

GIVEN: Wind direction and speed ....238°/15 k.

TC ....292°

GS ....176 k.

TO FIND: TH and TAS.



Solution

1. Select any point to represent point of departure. From this point draw the TC. Make the length of this line equal to the GS, 176 k.

2. From the end of this TC vector, plot the wind arrow from 238°. Remember that since wind blows the airplane from TH to TC, the **point** of this wind arrow touches the end of the TC vector. Make the length of this wind arrow equal to the wind speed, 15 k.

3. Connect the point of departure and the end of the wind vector opposite the arrow point with a broken line. The angle this broken line makes with true north is the TH, 288°. The length of this broken line is the TAS, 185 k.

DEAD RECKONING PROCEDURE

In pilotage you keep your airplane on course by watching the ground and noting your position in relation to the check points you have selected. You determine your GS by computing the elapsed time between check points. Then by using this GS and the distance to fly, you compute an ETA for any check point ahead of you.

In navigating by DR you have these same three objectives: (1) to keep your airplane on course; (2) to be able to determine your position on course at any instant of time; and (3) to determine correct ETA's. The difference is that in DR you do not use visible landmarks as the source of your information. Instead, you use the **wind**.

The success of your work depends vitally on your correct use of an accurate wind. Make every effort to determine **exactly** the speed of the wind and the direction from which it is blowing. Without this information you cannot navigate by DR. Furthermore, since wind is constantly changing, remember that you must check your wind at very frequent intervals during any flight. Whenever you discover that the wind has changed, you must determine the new direction and speed.

DETERMINE **EXACT** SPEED AND DIRECTION OF **WIND**

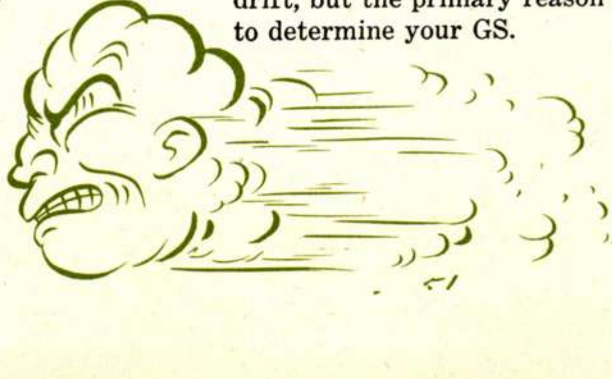
You can get wind information from two sources. Either the metro station can give it to you, or you can determine it yourself by taking what is called a **double drift**.

When the metro station can give you the wind before you take off, use this metro wind to determine a true heading to make good your course. Also use this wind to determine a GS on the true course you intend to make good, and with this GS compute your first ETA.

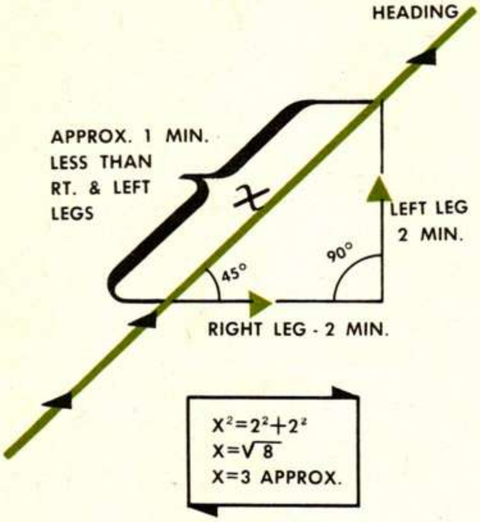
Do not rely entirely on a metro wind for your flight. Use it only to set course. As soon as you have set course, take a drift reading. If this reading shows that the drift is different from the one you got from metro information, correct for this drift to get a correct TH. Then by applying variation and deviation, get a correct compass heading.

If you do not have any metro information, use TC as TH, and as soon as you have set course correct it by taking a drift reading. This one drift reading will enable you to establish a correct heading for your flight. But in order to compute GS, you take a double drift within a few minutes after setting course. A correctly taken double drift always gives you completely reliable wind information.

A **double drift** is really a drift on **three** headings. To take a double drift, you first read from the drift meter the **drift on course**. Then the pilot turns 45° to the right of TH, and on the new heading flies either 2 or 3 minutes. You read the drift on this **right leg**. At the end of the time decided on, the pilot turns 90° to the left, and flies on this leg the same length of time he flew on the right leg. You read the drift on the **left leg**. Then the pilot turns back on to the original heading, and you determine wind and **GS** from the three drift readings you have taken. Notice that you obtain wind from taking a double drift, but the primary reason you take one is to determine your GS.



When you have taken drift on course, on the right leg, and on the left leg, you have drift on three headings. By plotting these drifts on the E-6B computer you can read an accurate wind and GS.



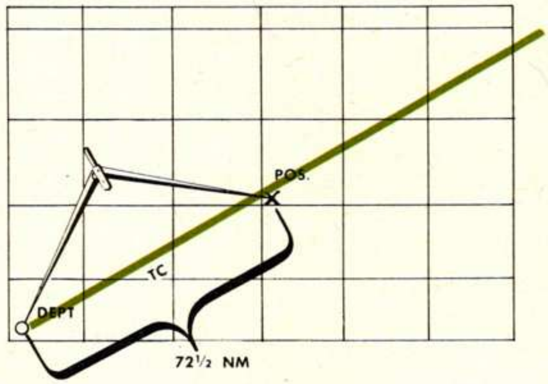
You know that accurate DR depends on reading your instruments accurately. But do not make the mistake of straining for a perfect reading by staying on the drift meter too long. The way to get a perfect reading is to read **quickly**. Fix an object between two grid lines and track it from the front to the back of the drift meter, keeping it parallel to the grid lines. This takes approximately 15 to 20 seconds. Then read your drift.

If you are tracking an object steadily and it suddenly jumps off to the right or left, disregard this sudden movement. It is not drift. The B-5 drift meter is not stabilized. Therefore if the airplane hits bumpy air the object will appear to drift sharply. Try to get an accurate drift when the pilot is holding the airplane steady.

When you take a double drift, remember that the pilot must fly the same time on each of the two legs. You and he decide in advance whether this time is to be 2 minutes on each leg or three minutes. If you fly 2 minutes on each leg, you have actually lost 1 minute of **flying time on course.** Therefore when you determine your position after taking a double drift, remember that the time from the last known position is **1 minute less** than the actual elapsed time. Similarly, if you fly 3-minute legs, the time is 2 **minutes less.**

You can use the accurate GS found by taking a double drift to determine your position at any time. To do this, set the known GS on your computer and opposite the number of minutes you have been flying **on course**, you read the distance you have flown. For example, suppose you want to determine your position after flying 30 minutes from departure. You have taken a double drift, using 2-minute legs. Therefore you subtract 1 minute to obtain 29 minutes, the actual time flown **on course**. From the double drift you found that your GS is 150 k. With 150 k. and 29 minutes set on the computer, you read the distance flown, 72½ nautical miles.

Extend your dividers to cover 72½ nautical miles on the mid-latitude scale, and on the TC line measure this distance from point of departure. The point 72½ miles out is the position after 30 minutes elapsed flying time. Always use the coordinates of this point to describe the position.



A position found in this manner is called a **position report** when you enter it in your log. A position report gives the location of the airplane at any given time. You can also predict your position ahead to determine where you will be after any specific time in flight. Thus position reports serve somewhat the same purpose in DR that check points do in pilotage. In pilotage, you use a check point to determine GS. In DR, you use GS to determine a position. You can always reckon ahead to a position and compute an ETA for that position.

THE DR LOG

To keep a record of a flight when you navigate by dead reckoning you use a log exactly like those used in pilotage. The procedure before take-off is exactly the same. Make all the necessary entries on the front page of the log, and on the work sheet fill out the first line. Notice, however, that in keeping a DR log you do not make any entries in the column labeled **To Next Check Point**.

In order to fill out the first line correctly, determine some time before take-off the coordinates of departure and destination and plot these points on the Mercator plotting chart. Draw the TC line connecting these two points and measure the angle of this TC you wish to make good. Also, measure the distance from departure to destination.

Before setting course, determine the TH necessary to make good the desired TC. If you have wind information from the metro station, use this information to determine the TH. If you do not have any wind information, use the TC as your TH.

Also before setting course determine a GS and use it to compute a time to destination. If you have a metro wind, use it to determine your GS. When you use a metro wind to determine GS, label the GS entry in the log "Metro." If you do not have wind information, use TAS as GS to compute an approximate time to destination.

Once you have determined the TH, apply variation to obtain a magnetic heading for the pilot. To this magnetic heading he applies deviation to obtain the correct compass heading, and sets course on this CH. You apply your deviation to the MH to obtain your own CH.

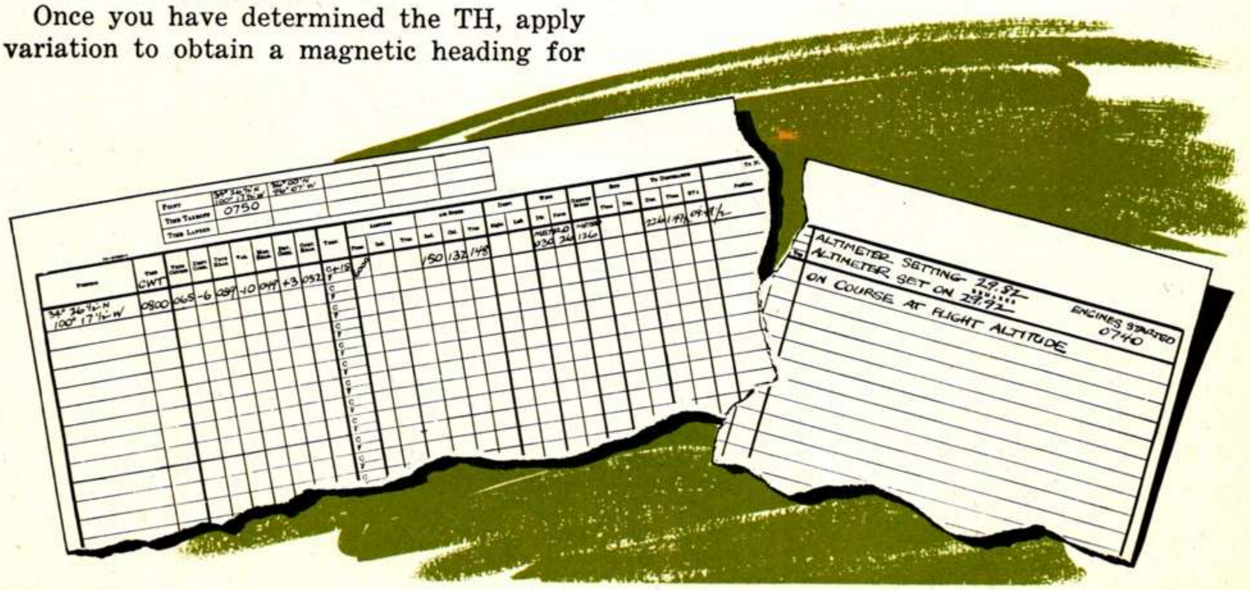
As soon as the pilot sets course check your compass reading and make sure that the airplane is flying on your compass heading. If it is not, note the number of degrees right or left necessary to bring the airplane onto your CH, and ask the pilot to make the correction.

Note the time when the pilot sets course, and compute an ETA for destination.

As quickly as possible after setting course, take your first drift reading. If the drift is different from the drift you used to determine your original TH, apply the new drift to the TC you wish to make good, and figure through to a new CH. Tell the pilot the number of degrees right or left he must turn in order to set course on this corrected CH.

Whenever you change CH as a result of a change in drift, enter on the next line of the log correct information under **Time, Drift Correction, True Heading, Variation, Magnetic Heading, Deviation,** and **Compass Heading.**

Throughout the flight, take readings from your drift meter and from all other instruments **every five minutes**. Make a new line of entries in your log for each set of instrument readings. For instrument readings, record drift correction, compass heading, temperature, altitude, and indicated airspeed.



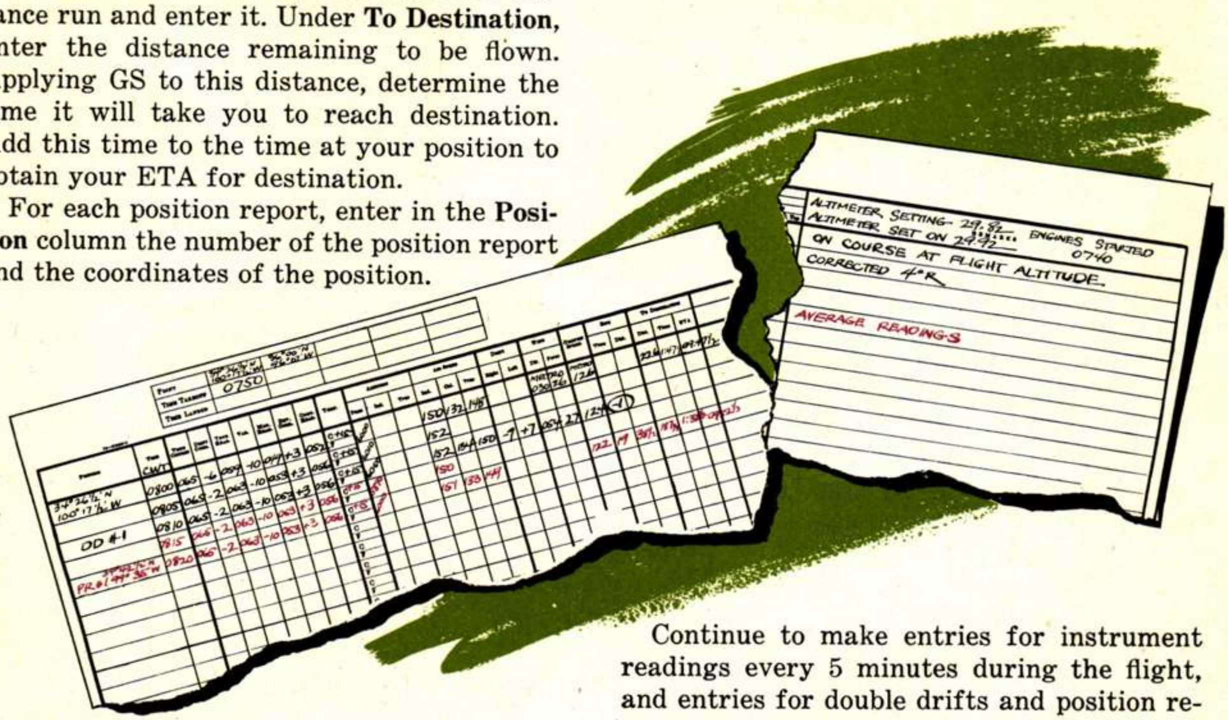
As soon as possible after you are sure the airplane is flying on the correct CH, take your first double drift. Enter the drift on both right and left legs in the appropriate columns. In the **Position** column, write "D.D. No. 1." Make the correct entries under **Time, True Course, Drift Correction** (on course), **True Heading, Variation, Magnetic Heading, Deviation, Compass Heading, Temperature, Altitude, Indicated Airspeed, Calibrated Airspeed, True Airspeed, Wind Direction, Wind Force,** and **Groundspeed.** In the **Time** column under RUN, be sure to enter either –1 or –2, and circle it. This entry is the time you lost when you took a double drift. You must subtract it from total elapsed time of flight to get the **time on course**. Remember that you use time on course with GS to compute distance traveled.

After you have taken a double drift and have obtained your GS, you can make a position report. You should make your first position report within the first 30 minutes of flight. Throughout the flight, take double drifts and make position reports at least once every 30 minutes.

When you make a position report, make a complete line of entries across the log through the column **To Destination.** For the entries under **Temperature, Altitude, Indicated Airspeed, Calibrated Airspeed,** and **True Airspeed** use the average of the readings recorded since the last position report. For this first position report, use the average of readings taken since departure. Using the average TAS and the wind, compute the average GS and enter it under **Groundspeed.** In the **Time** column under RUN, enter the

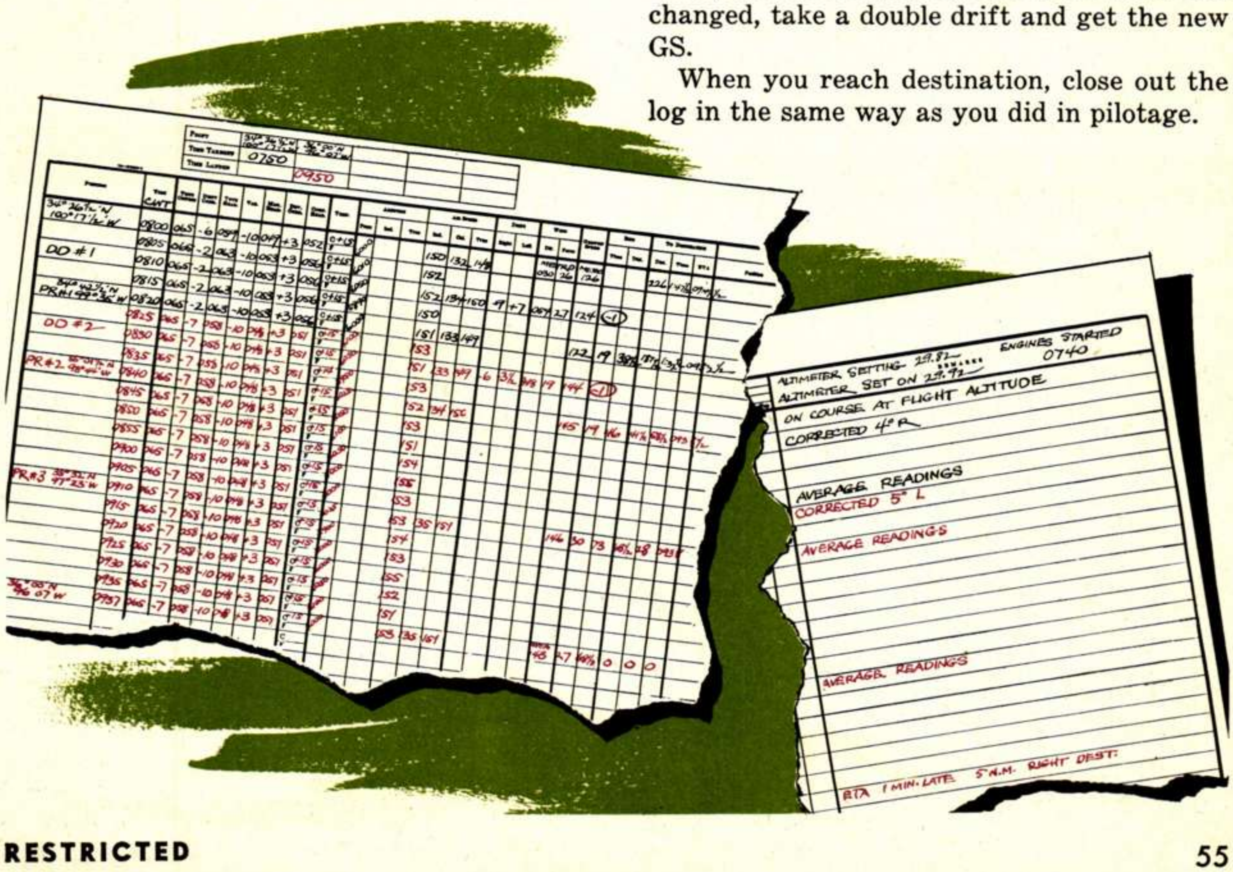
time **on course** from the last position, in this case from point of departure. Using the GS and the time on course, determine the distance run and enter it. Under **To Destination**, enter the distance remaining to be flown. Applying GS to this distance, determine the time it will take you to reach destination. Add this time to the time at your position to obtain your ETA for destination.

For each position report, enter in the **Position** column the number of the position report and the coordinates of the position.



Continue to make entries for instrument readings every 5 minutes during the flight, and entries for double drifts and position reports at least every 30 minutes. Also, whenever you have reason to believe the wind has changed, take a double drift and get the new GS.

When you reach destination, close out the log in the same way as you did in pilotage.



DOG LEG PROCEDURE

Sometimes you are given a course to fly on a dog leg, that is, you are told to fly from point of departure to destination **via** a specified turning point. You are given the coordinates of this turning point. The principal problem in navigating a dog leg course by DR is **to determine a correct ETA for the turning point**. Since in DR you cannot see the turning point, you have no other way of knowing when you have reached it.

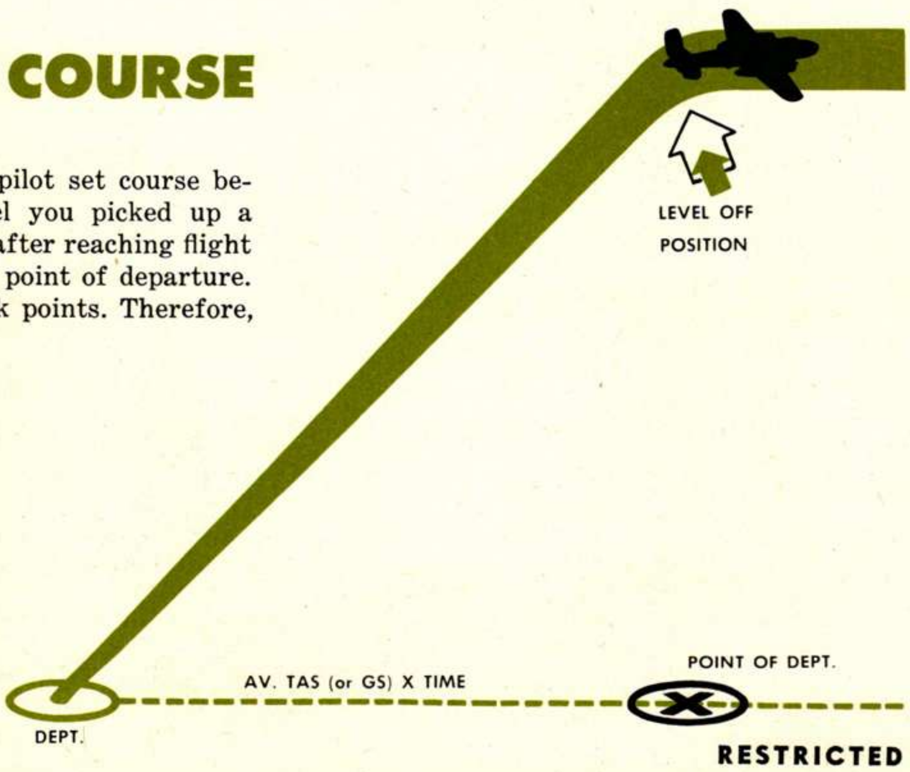
In flying the first leg of a dog leg course, consider the turning point as the destination. When you reach the turning point, close out the log and double line it. Then, using the last wind information, set course on the new leg, considering the turning point as the point of departure. Below the double line, make a complete new set of entries, using the new GS and ETA. Continue the log in the usual manner to destination, and close it out.

CLIMB ON COURSE

In pilotage, when the pilot set course before reaching flight level you picked up a check point immediately after reaching flight level and used it as your point of departure. In DR you have no check points. Therefore, when the pilot climbs on course you must locate the point where he levels off and use it as your point of departure.

To do this you must get the average GS during the climb. Take the average of your indicated airspeed readings and convert it to an average calibrated airspeed. Then using mean altitude of the climb and mean temperature, convert the average calibrated airspeed to an average TAS. If you have wind information, use it with the average TAS to compute your average GS. If you have no wind information, take the average TAS as the average GS.

Multiply the average GS by the time elapsed during climb to obtain the distance flown over the ground during the climb. With the dividers, measure this distance out on the course line from point of take-off. Locate the level-off position by its coordinates, and use it as the new point of departure for the flight.



POINTS TO REMEMBER IN KEEPING A *DR* LOG!

1. In making position reports, ALWAYS figure time and distance from your last known position. To find distance, use the GS from your last known wind. Do not use total time and total distance as you did in pilotage.

2. When you take a double drift ALWAYS use the instrument readings at that time. Do not use average readings.

3. When you make a position report, ALWAYS use average readings.

4. ALWAYS make complete entries of all known information on the first line, last line, and the lines used for **all** double drifts and position reports.

5. ALWAYS designate positions by coordinates.

6. Before take-off, ALWAYS set the pressure scale in the altimeter at 29.92, and read pressure altitude throughout the flight.

SPECIAL PROBLEMS

The radius of action of an airplane is the distance it can fly along a given course before it must turn either to its home base or to some pre-determined alternate base WITHOUT CUTTING INTO ITS RESERVE SUPPLY OF FUEL!

RADIUS OF ACTION

Since there is a limit to the amount of fuel an airplane can carry, there is a definite limit to the distance the airplane can travel without refueling. When you plan a mission it is fundamentally important that you determine accurately how far you can fly on the fuel allotted for the mission. You must determine how far you can fly **out**, but to compute this accurately you must include in your calculations the distance you must fly **back**, either to the same base or to an alternate base. The distance **out** is called **radius of action.**

You should ordinarily solve a radius of action problem on the basis of only 75% of your total fuel. In other words, reserve one-fourth of your fuel for a possible emergency. Plan to fly your airplane only three-fourths of the total time it could remain in the air on the allotted fuel.

There are two radius of action problems. One is the problem of determining where you must turn in order to come back to your **home base** on the available fuel without cutting into your reserves. The other is the problem of finding the correct turning point in order to reach an **alternate base.**

On any radius of action problem, you are always given the course out and the available fuel hours, that is, the total time you can remain in the air with the available fuel. You know the coordinates of the home base, and if you have an alternate base you know its coordinates also. Before take-off, you plot these positions on your Mercator chart, and plot the course line **out**.

When you reach flight altitude and the pilot has set course on the correct magnetic heading, you determine the TAS and the direction and speed of the wind. When you know available fuel hours, TC, TAS, and wind, you can determine your radius of action.

Problem No. 1: to Home Base

Suppose that you have enough fuel to fly a **total** time of 3 hrs. 21 min., and that your course **out** is 90°. After you set course you find that your TAS is 110 k. and from a double drift you find that the wind is 320°/10K.

First take three-fourths of your total available fuel hours, in order to keep a reserve supply. This gives you 2 hrs. 31 min. of flying time for your mission without cutting into your reserves. Since you lost 1 minute of on course time by taking a double drift, you must subtract 1 minute from this total available time to find the total time you can afford for the entire mission. Designate it as capital T (T= 2 hrs. 30 min.).

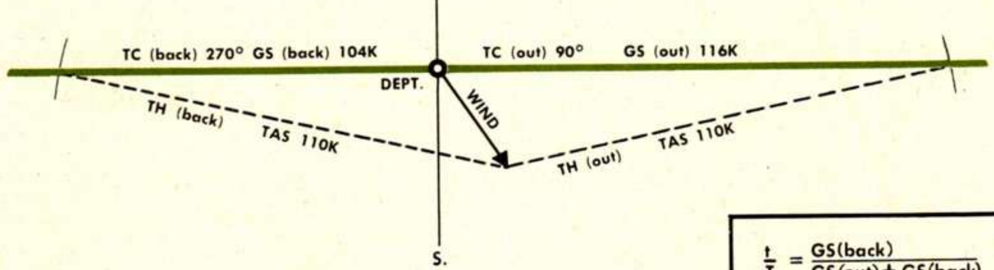
You have plotted your TC **out** from the coordinates of your home base. Place the ruler on this line and extend the line from the home base in the **opposite direction**. This line is the reciprocal (270°) of the TC, and represents the TC **back.**

From the home base, plot the wind vector of 320°/10K. Extend the dividers TAS distance (110 k.) and place one pointer on the point of the wind arrow. Swing the dividers to intersect the TC **out**. Connect the point of intersection and the point of the wind arrow with a broken line. This broken line is the TAS and TH vector **out**. With the dividers, measure the distance on the TC **out** from home base to the point of intersection. This distance is the GS **out** (116 k.).

In the same way, extend the dividers TAS distance and swing them from the point of the wind arrow to intersect the TC **back**. Connect point of intersection and point of wind arrow with a broken line. This broken line is the TAS and TH vector **back**. On the TC **back**, determine the GS **back** (104 k.).

The time you can fly on TC **out** before turning back is called small **t**. You can determine the values of small **t** by using the following equation:

$$\frac{t}{T} = \frac{\text{GS back}}{\text{GS out} + \text{GS back}} \text{ or } \frac{t}{2 \text{ hrs. } 30 \text{ min.}} = \frac{104}{220}$$



$$\frac{t}{T} = \frac{GS(back)}{GS(out) + GS(back)}$$

then

$$R/A = GS(out) \times t$$

WORK THIS ON THE E-6B COMPUTER. Set 220 on the inner scale opposite 104 on the outer or miles scale. Then opposite 2 hrs. 30 min., or 150 min., on the inner scale, read 71 min. on the outer scale. Small **t** = 71 min., or 1 hr. 11 min. This is the **time** you can fly on the TC **out** before turning.

You must tell the pilot when to turn back. That is, you must give him the ETA for the turning point. If your small **t** is 1 hr. 11 min. and you lost 1 min. of on course time when you took a double drift, the elapsed time from departure to turning point is 1 hr. 12 min. Then the ETA for the turning point is the time of departure plus 1 hr. 12 min.

For example, if you departed on this mission at 0800 and took one double drift using 2-min. legs, you would tell the pilot to turn at 0912.

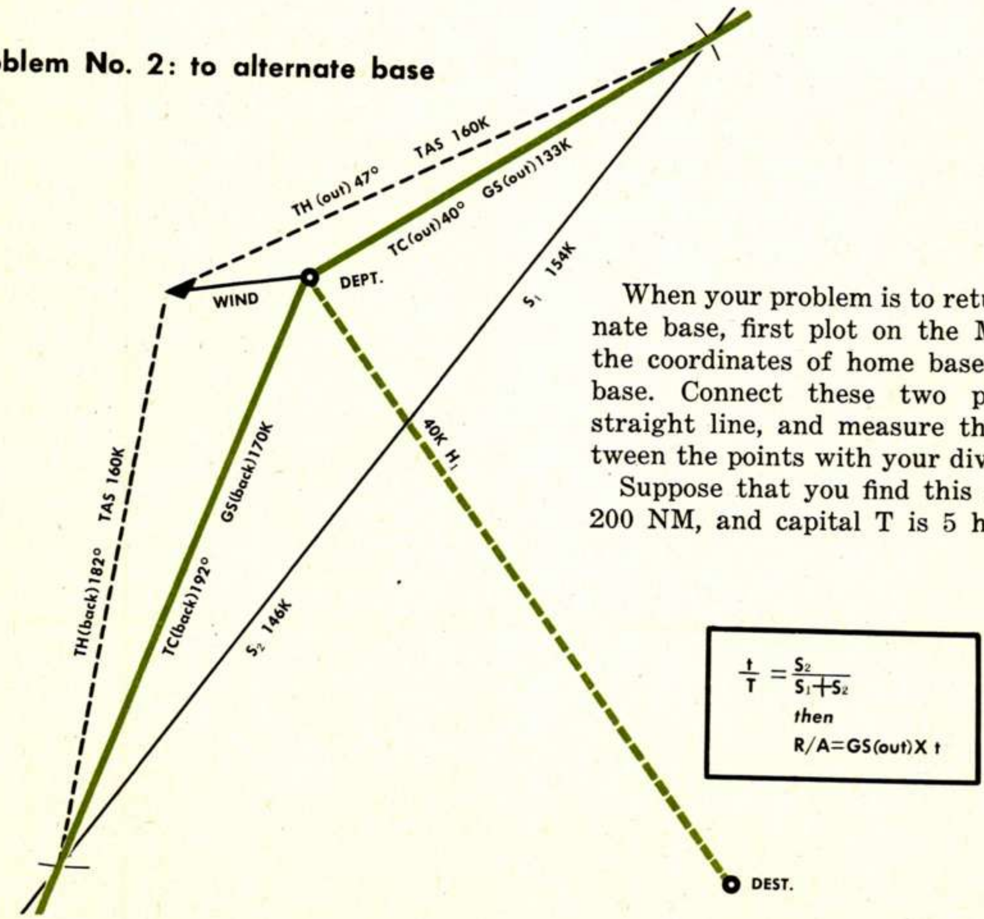
To find the **distance** you can fly out, or your **radius of action** (R/A), solve the following equation ON THE COMPUTER as a rate, time, and distance problem:

$$R/A = GS\ \mathbf{out} \times t$$

Set the black pointer under 116 on the outer scale. Opposite 71 min. on the inner scale, read 137 nautical miles on the outer scale. R/A = 137 NM. To determine the **position** of the turning point, measure on the TC **out** line 137 NM from home base and mark. Then locate this point by its coordinates.

To find the ETA for the home base, take the time of departure from home base and add capital T **plus** the time lost when taking double drifts. Thus if you depart on the mission at 0800, if T is 2 hrs. 30 min. and if you take one double drift using 2-min. legs, the ETA for home base is 1031.

Problem No. 2: to alternate base



When your problem is to return to an alternate base, first plot on the Mercator chart the coordinates of home base and alternate base. Connect these two points with a straight line, and measure the distance between the points with your dividers.

Suppose that you find this distance to be 200 NM, and capital T is 5 hrs. Remember that this means you can fly 5 hrs. and still have one-fourth of your total fuel in reserve. Your TC **out** is 40°, the wind is 80°/30k, TAS is 160 k.

Plot your TC **out** (40°) from the home base. Also from home base, plot the wind vector. Then extend the dividers TAS distance and with one pointer on the point of the wind arrow swing the dividers to intersect the TC **out**. Draw a broken line from this point of intersection to the point of the wind arrow. This broken line is the TH **out** (47°) and TAS vector. With the dividers, measure the distance on the TC **out** from home base to the point of intersection. This distance is the GS **out** (133 k.).

In order to construct a vector triangle which will give you your TC **back** and TH **back**, you must first find the quantity called **hourly increment** (HI). HI is the **rate** you get when you divide the distance between home base and alternate base by the total time. That is, $HI = \frac{\text{Distance}}{T}$. In other words, HI is the **average** rate at which you approach the alternate base when you take off from the home base and remain in the air T hours. In this problem, $HI = \frac{200}{5} = 40$ k.

Now on the straight line connecting home base and alternate base, measure the HI for 1 hr., or 40 NM, from home base, and mark. Label this point HI.

From the point where TC **out** and TH **out** intersect, draw a long line through point HI. Label S_1 the segment from point of intersection to HI. Label S_2 the segment extending beyond HI.

Extend the dividers TAS distance and with one pointer on the point of the wind arrow swing the dividers to intersect S_2. From this point of intersection draw a solid line to home base and a broken line to the point of the wind arrow. The solid line is TC **back** (192°) and its length is GS **back** (170 k.). The broken line is TH **back** (182°) and its length is of course TAS. The line from HI to the point where TH **back** and TC **back** intersect is S_2.

The segment S_1 represents the rate of departure from HI, and the segment S_2 represents the rate of closure with HI. Measure these segments with your dividers. ($S_1 = 154$ k.; $S_2 = 146$ k.). You must know these rates in order to compute small **t**.

You can determine the value of small **t**, the time you can fly on TC **out** before turning, by using the following equation:

$$\frac{t}{T} = \frac{S_2}{S_1 + S_2} \text{ or } \frac{t}{5} = \frac{146}{300}$$

WORK THIS ON THE E-6B COMPUTER. Set 300 on the inner scale opposite 146 on the outer scale. Then opposite 5 hrs. or 300 min. on the inner scale, read 146 min. on the outer scale. Then small t = 146 min., or 2 hrs. 26 min., which is the time from departure to turning point. Add 2 hrs. 26 min. to time of departure to obtain the ETA for the turning point. Give this ETA to the pilot.

Find your R/A, or the distance from home base to turning point, by the equation:

$$R/A = GS\ \textbf{out} \times \textbf{t}.$$

Solve this on the computer by setting the black pointer under 133. Then, opposite 146 min. on the inner scale, read 323 nautical miles on the outer scale.

To determine the **position** of the turning point, measure on the TC **out** 323 NM from home base and mark. Then locate this point by its coordinates.

NOTE: If you take a double drift in a radius of action problem to an alternate base, remember to allow for the time lost when you compute capital T and also when you compute an ETA for the turning point. Remember also that to compute an ETA for alternate base, you add capital T plus time lost on double drifts to time of departure.

If the wind changes appreciably on the TC **out**, you must work a new R/A problem from the point where you estimate that the wind changed. If the wind changes on the TC **back**, simply change your heading to correct for the new drift and fly on in to the alternate base. In this event you will arrive either before or after the expiration of T, but since you have a reserve supply of fuel you need not worry about it.

A quick way to check on the accuracy of your work is to plot TC **back** through turning point. If your work is accurate, this line, extended, will pass through alternate base.

INTERCEPTION

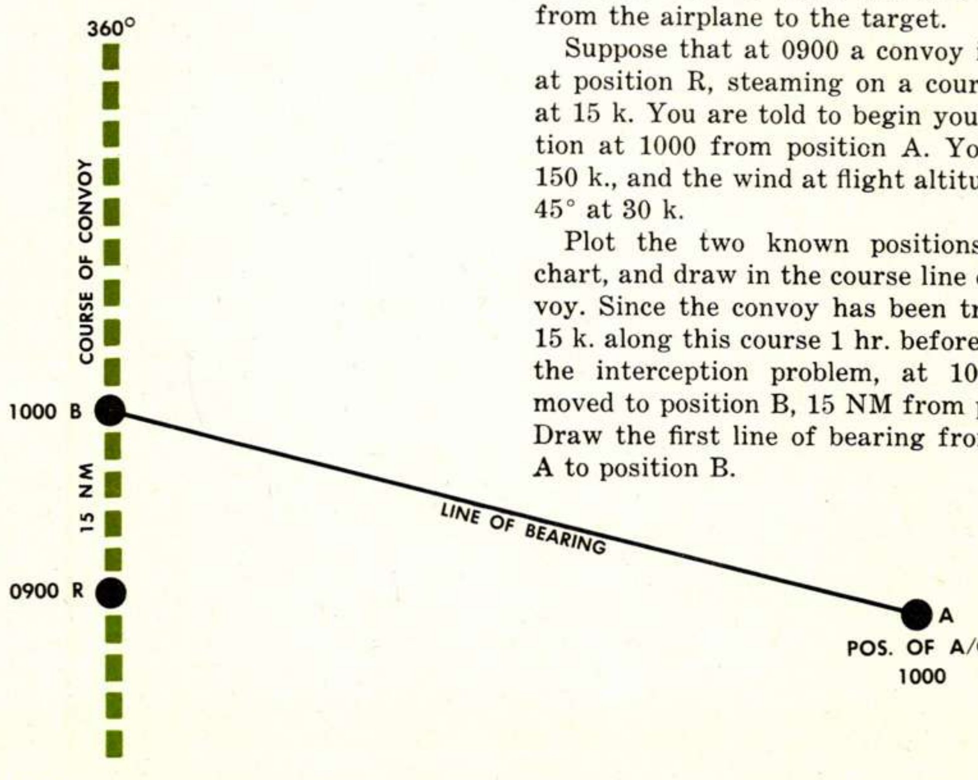
The interception problem is the method used to determine what course you must fly in order to intercept a target moving along a different course. For example, you may be told to take off from San Diego and fly out to a ship which is steaming at a known speed on a direct course from San Francisco to Honolulu. Your problem is to determine what course you must fly in order to reach some point on the ship's course at the moment the ship reaches that same point.

When you have an interception problem, you are always given the position, course, and speed of the object to be intercepted. You must know also the wind that is affecting your airplane and your TAS. When these five factors are known you can determine the TC you must make good.

The first thing you do is plot on a Mercator chart the position of your airplane **at the time you begin the interception**. Then plot the position of the target AT THIS SAME TIME. Draw a straight line connecting these two points and determine the direction of this line. This is called the **line of bearing** from the airplane to the target.

Suppose that at 0900 a convoy is reported at position R, steaming on a course of 360° at 15 k. You are told to begin your interception at 1000 from position A. Your TAS is 150 k., and the wind at flight altitude is from 45° at 30 k.

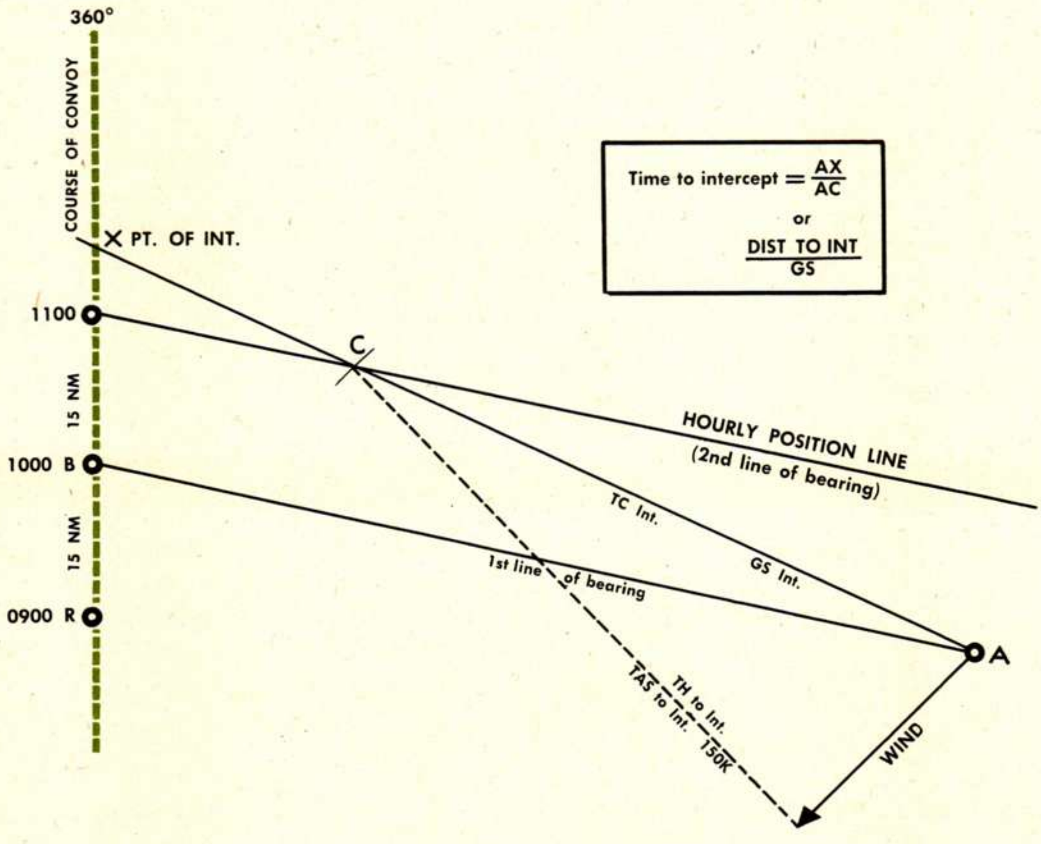
Plot the two known positions on your chart, and draw in the course line of the convoy. Since the convoy has been traveling at 15 k. along this course 1 hr. before you begin the interception problem, at 1000 it has moved to position B, 15 NM from position R. Draw the first line of bearing from position A to position B.



In order to intercept the convoy somewhere along its course in the shortest possible time, you need to make good a TC which is a straight line. To find this straight line course, first determine where the convoy will be along its course after 1 hr., or at 1100. Through this 1100 position, 15 NM along the convoy's course from position B, plot a line parallel to your first line of bearing. In order to fly a straight line course which will intercept the convoy, your airplane must be somewhere along this second line of bearing at 1100. In other words, to solve your interception problem, your airplane must maintain a **constant line of bearing** to the convoy.

Next plot the wind arrow from position A, which is the point where the airplane begins the interception problem. Extend the dividers TAS distance and place one pointer on the point of the wind arrow. Swing the dividers across the second line of constant bearing and label the point of intersection "point C." Connect point C and the point of the wind arrow with a broken line. The direction of this line is your TH. Point C must be the position of your airplane at 1100.

Complete the vector triangle by drawing the TC line from position A to point C. Extend this TC line until it intersects the course of the convoy at point X. Point X is where your airplane will intercept the convoy. The length of the line from position A to point C is your GS. The length of the line from position A to point X is **distance to intercept.**

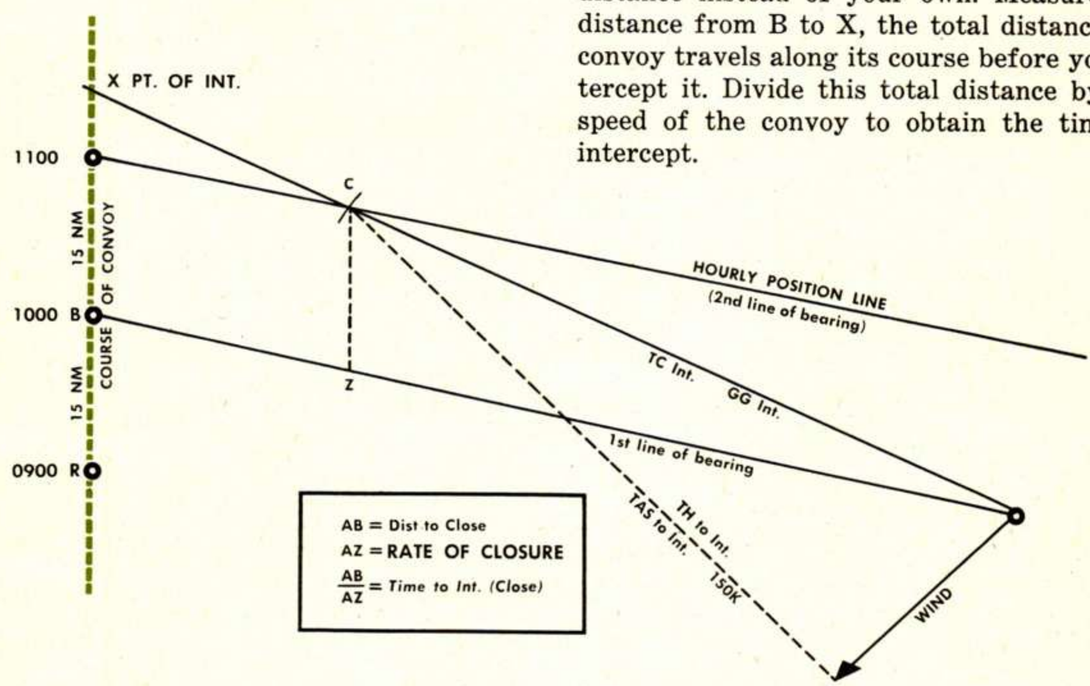


To find the time it will take you to fly from position A to point X, or time to intercept, measure the total distance to intercept and divide by GS. Add this time to the time you begin the interception to obtain an ETA for the point of interception.

There are two other methods of determining the time to intercept. The first method uses what is called the **rate of closure** and **distance to close**. The distance to close is the length of the line from position A to position B. It is the distance which the airplane must move toward the convoy in order to intercept it. The rate of closure is the rate at which the airplane closes this distance.

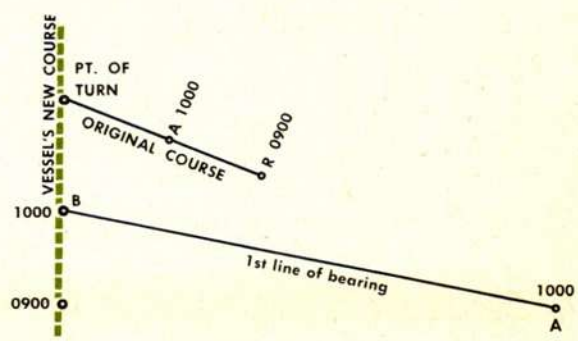
To find the rate of closure, draw a line from point C parallel to the course of the convoy and intersecting the line AB at a point. Label this point Z. The distance from position A to point Z is the rate of closure. That is, it is the distance the airplane moves toward the target in 1 hr. Divide the distance to close by the rate of closure to obtain time to intercept.

A second method of determining the time to intercept is to use the convoy's speed and distance instead of your own. Measure the distance from B to X, the total distance the convoy travels along its course before you intercept it. Divide this total distance by the speed of the convoy to obtain the time to intercept.

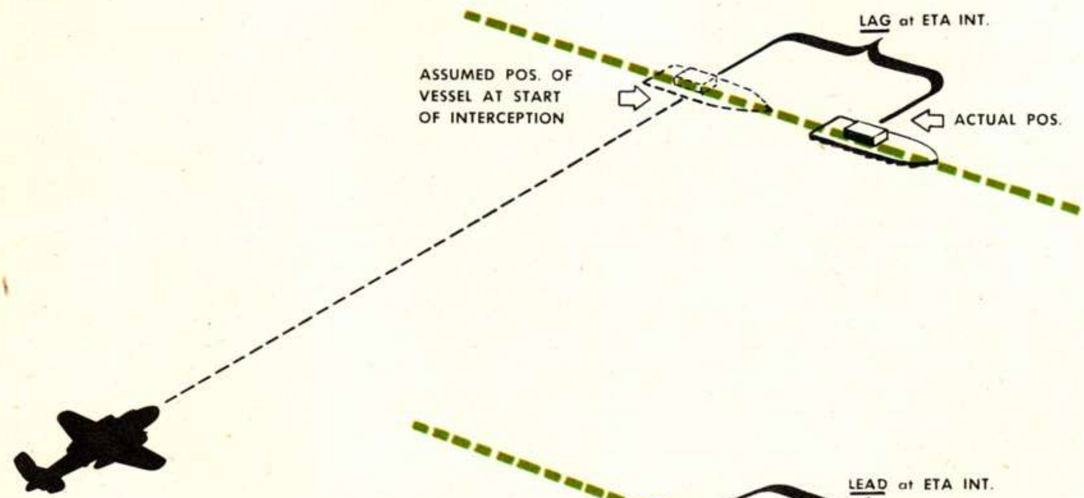


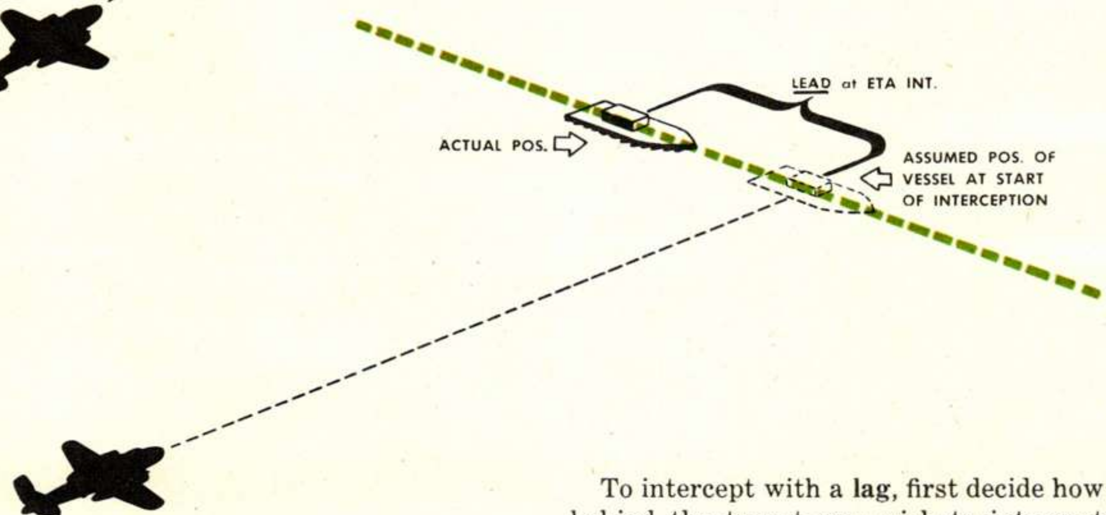
You have a special problem of interception if you know your target will change its course during the interception. Plot on the Mercator chart the position at which the target will turn and the new course it will make good. Extend the reciprocal of this new course back from the turning point.

Then, in order to solve your problem, you **assume** that the target has been on the new course during the entire time of the interception. On the reciprocal of this new course, plot the position where the target would have been at the beginning of the interception. Draw the first line of bearing from this position to the original position of the airplane, and solve an interception problem from these two positions.



On some occasions you may wish to intercept the **course** of the target instead of the target itself, in order to turn and make your run over the target from dead ahead or dead astern. An interception of the course ahead of the target is called a **lead**; interception of the course behind the target is called a **lag**.





To intercept with a **lag**, first decide how far behind the target you wish to intercept its course. Then before plotting the interception, move the target **back** this distance on its course, and use this new position as the ship's position at the beginning of the interception. To intercept with a **lead**, move the ship **forward** along its course.

In intercepting with either a lead or a lag, compute your ETA for interception very accurately. You must know it in order to know when to turn in on the course of the target.

SEARCH AND PATROL

A **search** is a flight performed for the purpose of locating an object which you know or believe to be somewhere in a given area. A **patrol** is a flight performed for the purpose of keeping a given area under observation.

To prevent aimless flying and to insure that the area is covered thoroughly, search missions and patrol missions are flown in definite **patterns.**

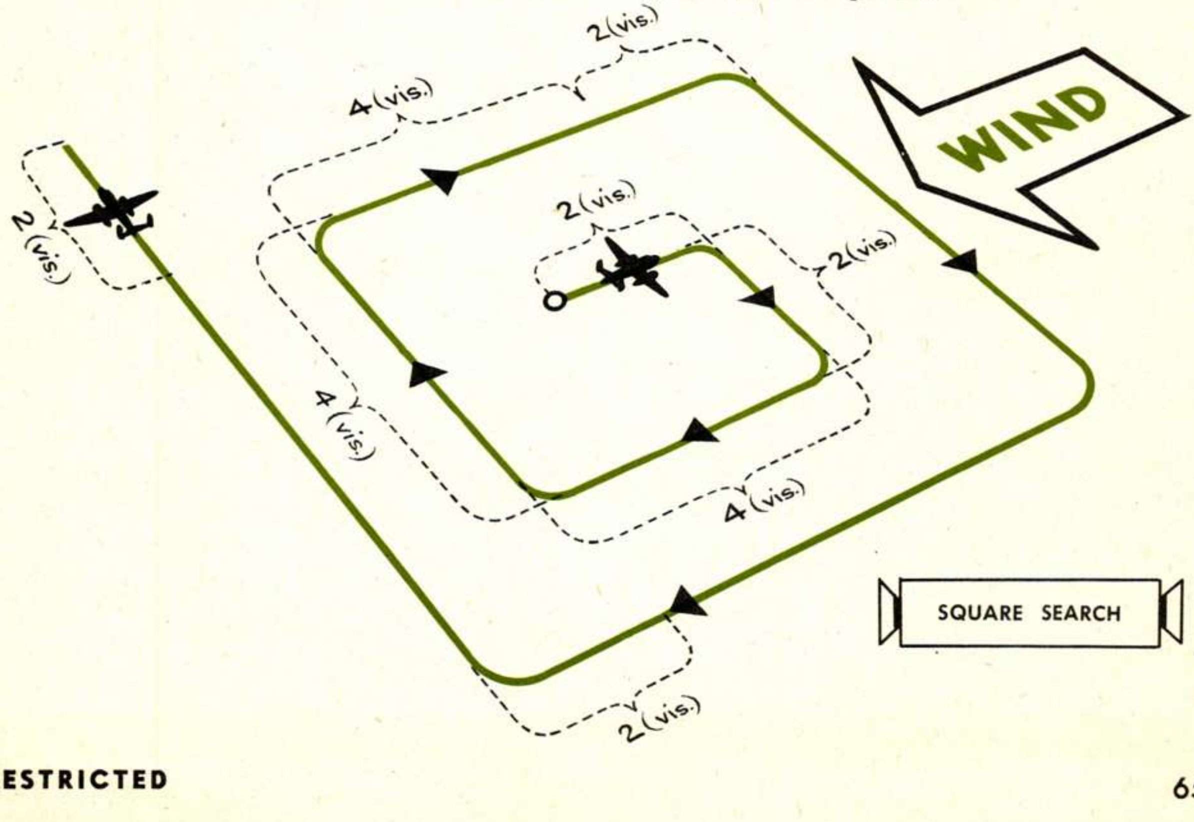
The most common search pattern is the expanding square. To fly this pattern, first determine the visibility in terms of miles, and select a position from which to begin the search. From the starting position fly **twice visibility distance** in any fixed direction. In other words, if the visibility is 10 miles, fly 20 miles on this first leg. It does not matter in which direction you fly the first leg, but it is wise to fly it upwind because this gives you a little more time for your first calculations.

When you have flown twice visibility distance on your first leg, alter course 90° either to the right or to the left. On the new course, fly twice visibility distance to your second turning point.

At the second turning point, alter course again 90° to the right or left according to the way you turned at the first turning point. If you alter course to the right at the first turning point, you must make **all** turns to the right. On this third leg, fly **four times** visibility distance. When you complete this leg, alter course again 90° and fly the fourth leg **four times visibility** distance.

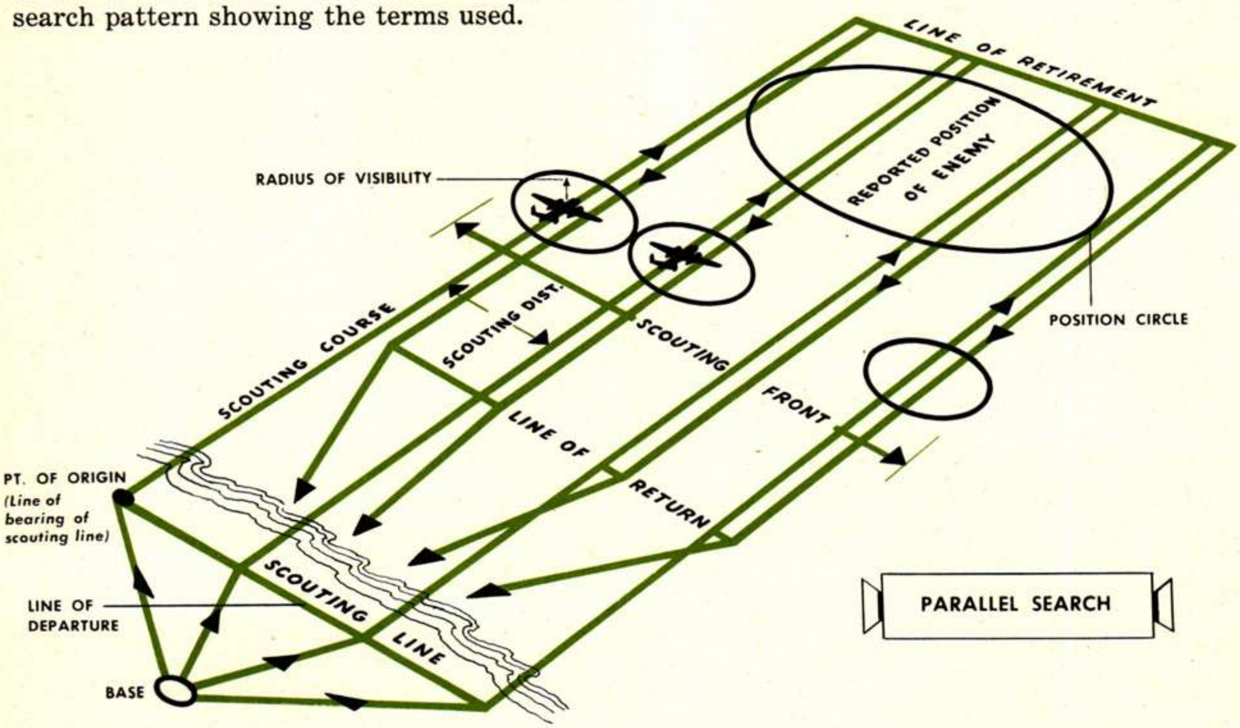
Continue this pattern, increasing the length of each new pair of legs by twice visibility distance. Thus if visibility is 10 miles, make the first and second legs 20 miles long, the third and fourth 40 miles, the fifth and sixth 60 miles, **etc.** This method assures that you see the whole area. To be doubly sure, you can use less than twice visibility as your unit of measurement. This gives you an overlap of visibility on each leg.

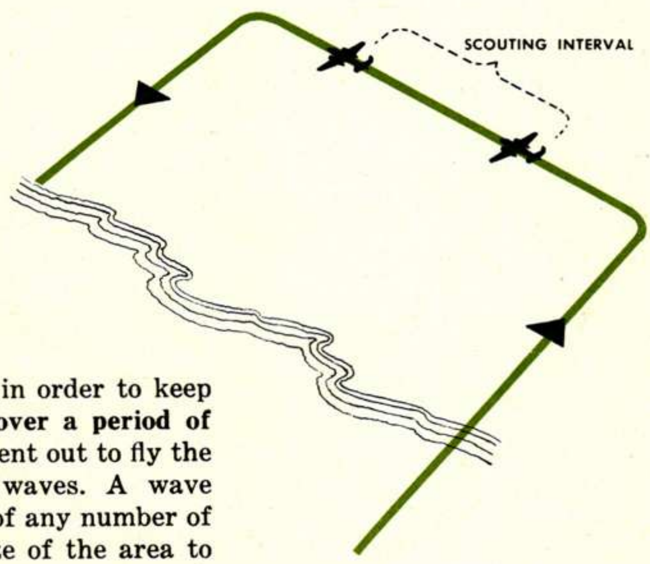
This pattern is very useful. If you fail to find your target at the end of an interception problem, you can usually find it by flying an expanding square search, starting at the position where you expected to intercept the target. Also at the end of any mission if you are not over your destination you can locate it by using this pattern.



SQUARE SEARCH

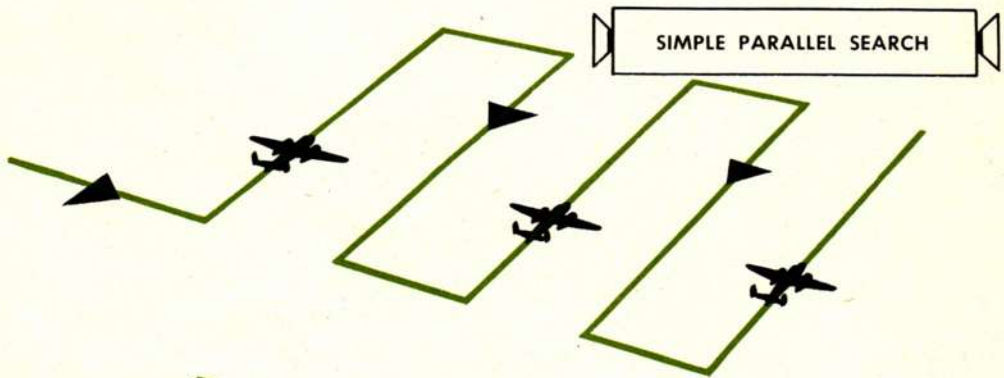
Search missions and patrol missions often involve several airplanes or "scouts." Patterns for these flights are planned to assure that every point within the area will be seen by one or more of the scouts. Here is a typical search pattern showing the terms used.

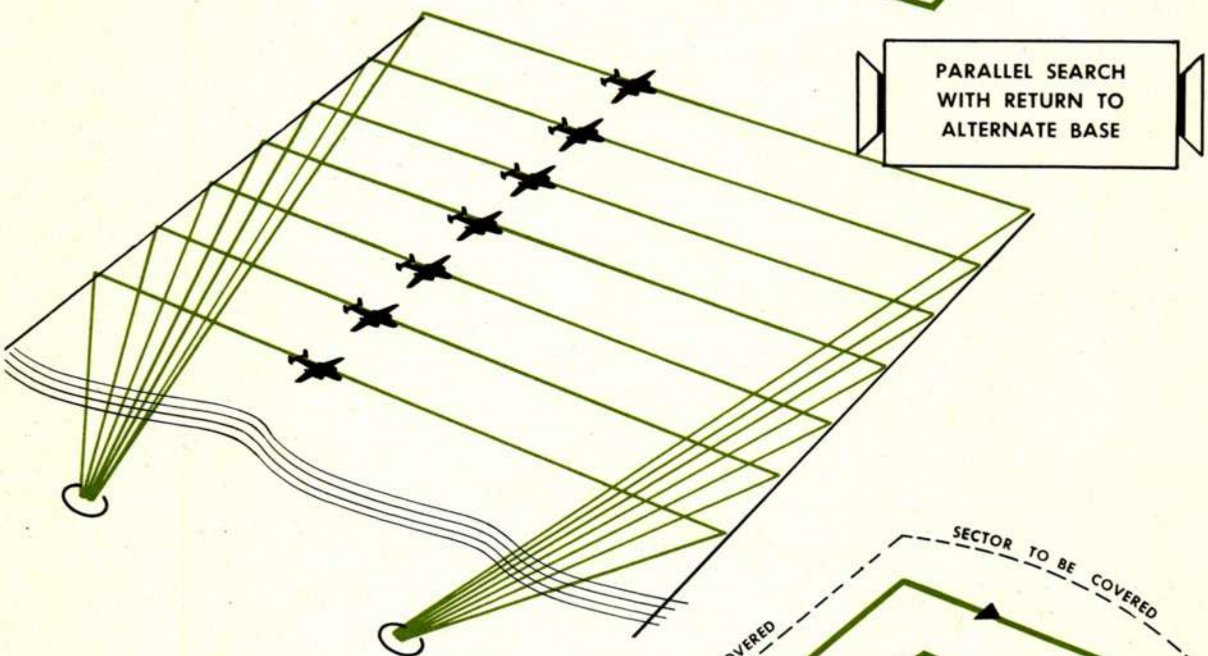


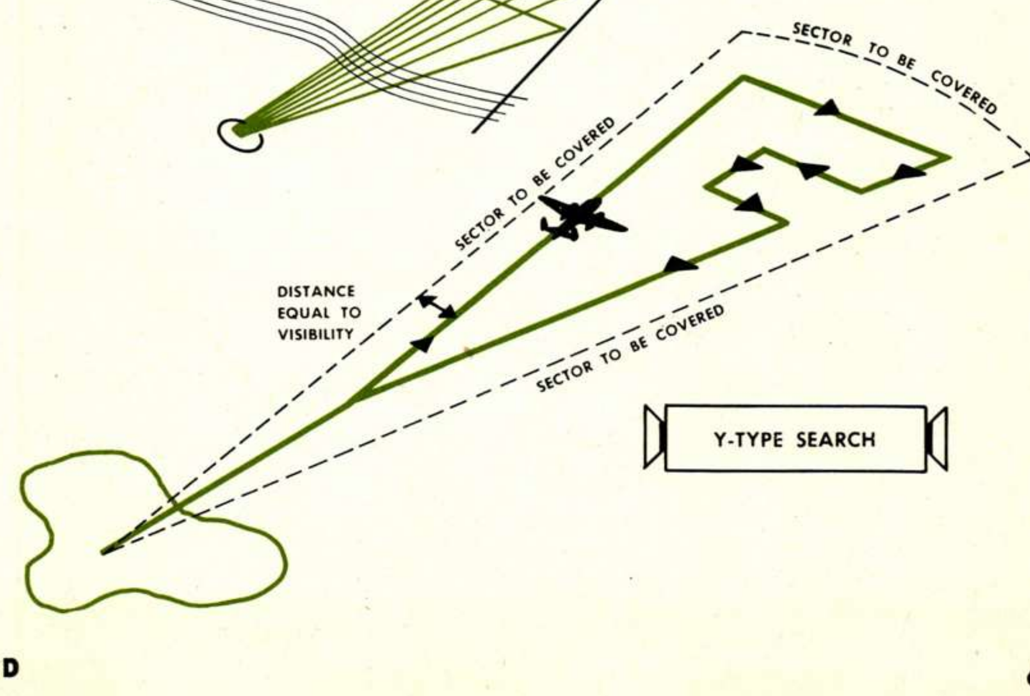


A patrol mission is flown in order to keep an area under observation **over a period of time.** Therefore, scouts are sent out to fly the pre-determined pattern in waves. A wave may consist of one scout or of any number of scouts, depending on the size of the area to be patrolled and the pattern to be used. Waves are normally sent out at regular intervals of time. The **distance** between any two waves is called the **scouting interval.**

When you are sent on a search mission or a patrol mission, you are given the pattern and instructions for flying it in the briefing room. Here are some standard search and patrol patterns.





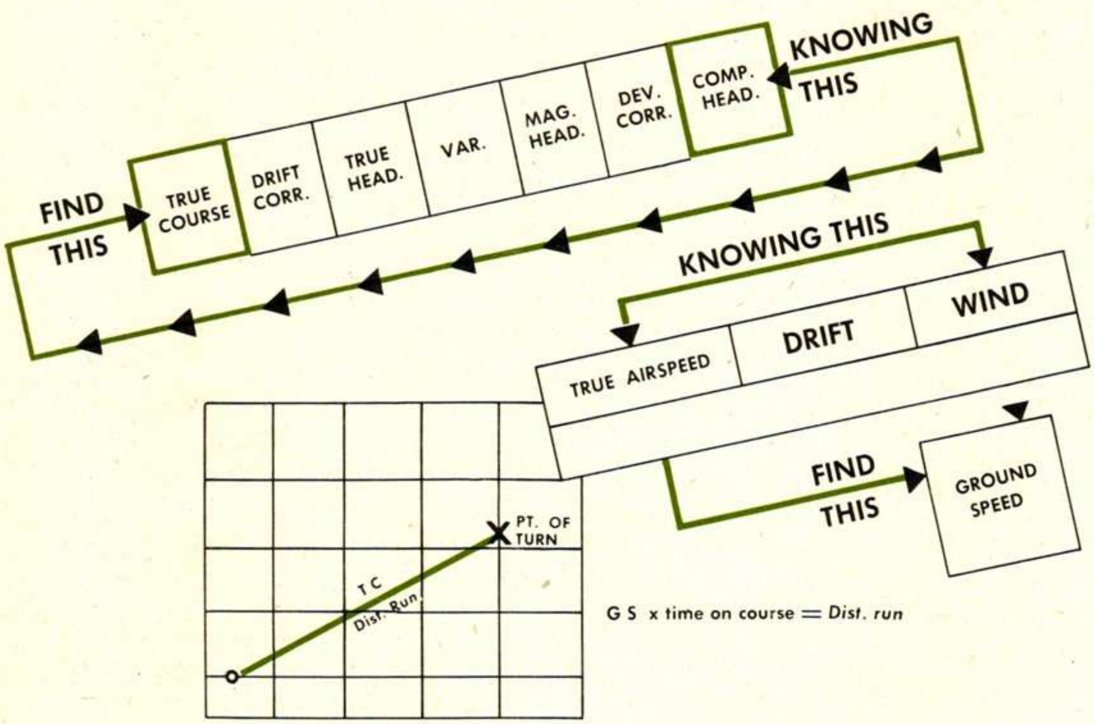


FOLLOW THE PILOT (Air Plot Method)

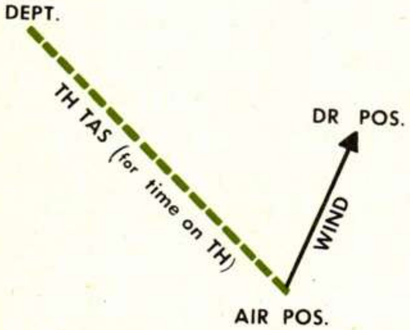
Normally the pilot follows the directions given him by the navigator. Very often, however, he is forced to fly on different headings and at different altitudes and airspeeds from those you have planned. If you run into a storm on the course you have plotted, the pilot will take over and detour around it without directions from the navigator. Also, for tactical reasons he may have to alter course and fly on his own for a short time.

When this happens, you must "follow the pilot," that is, you must keep track of the movements of the airplane in order to determine its position when the pilot is ready for you to direct it again. Unless you can locate the position of the airplane accurately you cannot plot a course into destination.

There are two methods you can use to follow the pilot accurately. Each time the pilot alters course you know the new compass heading and TAS he is flying. By one method of following the pilot you find the TC by reversing the normal DR procedure, IF YOU KNOW THE WIND. By applying deviation, variation, and drift corrections to the compass heading, you obtain the TC and plot it. Then by using the GS and the time you fly on the TC you determine the length of the leg and the position of the airplane at the turning point. If you continue this method on each leg, you can determine the position of the airplane in relation to destination.

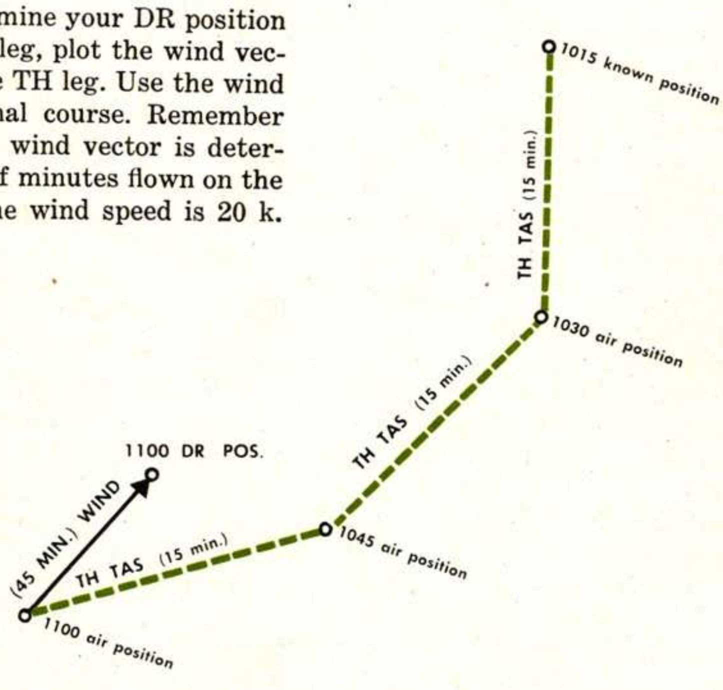


A quicker method of following the pilot is the **air plot** method. By this method you plot only the TH and TAS vector. Using the TAS and the time you fly on the TH, you can determine the length of the leg. Then you can plot the position of the turning point **in relation to the body of air**. This is called the **air position**. Notice that it is not your **DR position** in relation to the ground.



If you want to determine your DR position at the end of only one leg, plot the wind vector from the end of the TH leg. Use the wind you had on the original course. Remember that the length of the wind vector is determined by the number of minutes flown on the leg. For example, if the wind speed is 20 k. and you fly 15 minutes on the leg, the wind vector is 5 NM long. Your DR position is at the point of the wind arrow. REMEMBER: wind always blows the airplane **from** TH **to** TC made good.

If the pilot flies two or more legs before you need to determine your DR position, do not waste time plotting your DR positions at each turning point. Simply plot the various turning points at the ends of the various TH lines. That is, plot the air positions. Then from the end of the last leg, plot the wind vector. You can determine this wind accurately from the drift readings you have taken on the various headings. The length of the wind line is determined by the **total** number of minutes you have been following the pilot. The coordinates of the point at the end of this wind line give you the **DR position** of the airplane.



To solve an actual follow-the-pilot problem by the air plot method, suppose that your pilot encounters a storm and is forced to turn off course. He alters course at 1015 to a CH of 170°. Deviation on this heading is +6° and variation is 16° E. Working backward, you determine the TH of 180°, and your drift meter shows a drift correction of +7°. The pilot holds his heading constant for 15 minutes and you determine that the average TAS for this period is 147½ k. Plot the TH line, and when the pilot turns onto a new heading note the time and plot the air position of the turning point.

At 1030 the pilot turns to a new compass heading of 202°. Deviation on this heading is +2°. Variation, of course, remains the same, 16° E. At the same time, the pilot climbs 2,000 ft., and you note that your TAS now is 164 k. Determine the TH of 216°, and read the drift correction of +4½°. Plot your TH line and watch the time. The pilot turns onto a new heading at 1045. Using the 15 minutes flown on this leg and the new TAS of 164 k., determine the coordinates of the turning point and plot the air position.

The CH on the third leg is 244°, and deviation is +10°. TAS remains 164 k. TH now is 250° and the drift correction is –2°. When the pilot turns onto this third heading at 1045, he tells you that he intends to hold this heading for 15 minutes. He wants to know what the DR position of the airplane will be at 1100 because at that time he wants to set course for destination.

On the TH line, measure ahead 15 minutes from the beginning of this third leg to determine your **air position**. From your drift readings on the three headings, determine the wind 242°/21k. Plot this wind **from** your air position. Since the total time flown on the three legs is 45 minutes, take three-fourths of 21, or 16. The length of your wind line is 16 NM. The point at the end of this wind line is your **DR position** at 1100.

Once you have determined this DR position, plot the TC in to destination. Then using the known wind, determine the TH and the GS. By applying variation to the TH, find the magnetic heading and give it to the pilot. Using GS and distance, compute the ETA for destination.

POINTS TO REMEMBER IN PLOTTING AND LOGGING AN AIR PLOT

1. Be sure to use on the Mercator chart *average* TAS and *average* TH for each leg.

2. If the wind changes during an air plot, use the *average* wind to plot the final wind vector.

3. ALWAYS plot wind *from* TH.

4. You can start an air plot from any position provided it is a *definitely known position*.

5. Label your air plot work to prevent confusion with any other work you may have on the Mercator chart.

6. On the log, always enter the coordinates of the turning points in the *Position* column. Label these entries "*AP*" to remind yourself that these are air positions and not DR positions.

7. Each time you alter course, *double line the log*.

8. Don't forget to make 5-minute entries of instrument readings *in order to get true averages*.

CONTROLLED GROUNDSPEED

It is frequently necessary for an airplane to reach a destination at a specified time. When airplanes take off from different fields for a bombing mission, for example, they must meet at a given time at some pre-determined rendezvous to join their formation. In such a situation, the navigator in each airplane must determine the GS he must make good in order to reach the point at the required time. Then he must determine the indicated airspeed necessary to make good this GS.

This controlled groundspeed problem is very simple. You first plot the TC. Then divide the distance from departure to destination by the length of time allotted for the flight. This gives the GS you must make good. Setting the TC, GS, and the wind direction and speed on the E-6B computer, you determine the TAS you must make good. Then by applying pressure altitude and temperature at flight level to this TAS, you can determine the calibrated airspeed. Convert this CAS to the indicated airspeed at which the pilot must fly in order to make good the required GS.

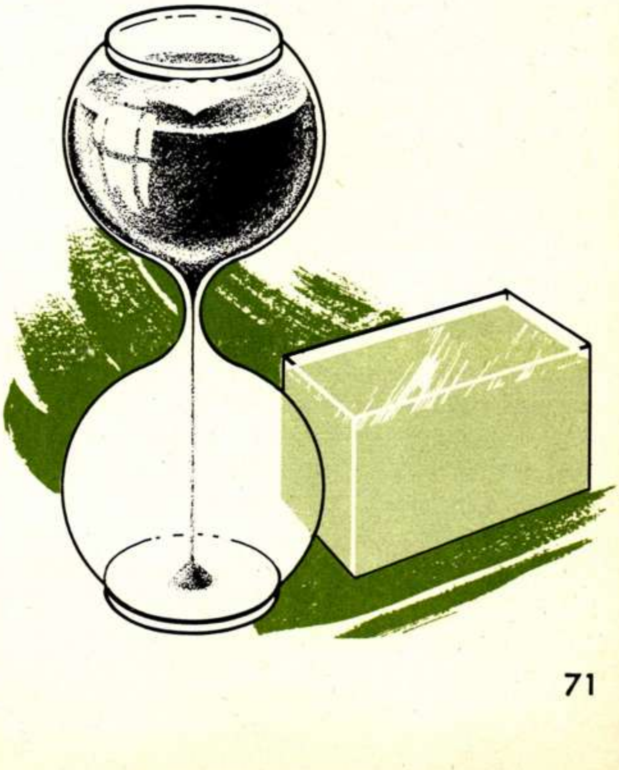
Suppose you are required to fly 105 miles in 30 minutes, along a TC of 300°. Set up the distance, rate, and time problem on your computer, and read the GS of 210 k. which you must make good. The wind is 90°/28k.

With the TC, GS, and wind on the transparent face of the computer, determine the TAS of 186½ k. which you must make good. On the other side of the computer, match the pressure altitude of 11,000 ft. and the flight level temperature of 0° in the airspeed computation window. Then, opposite 186½ on the outer scale, read the CAS of 155 k. on the inner scale. Then from your calibration card read the correct indicated airspeed **in miles per hour.** In this particular problem, assuming no installation or instrument error, the IAS is 178 mph. Give the pilot the IAS to fly.

The controlled GS problem is simply a reversal of the familiar DR procedure where you determined GS by using wind and instrument readings.

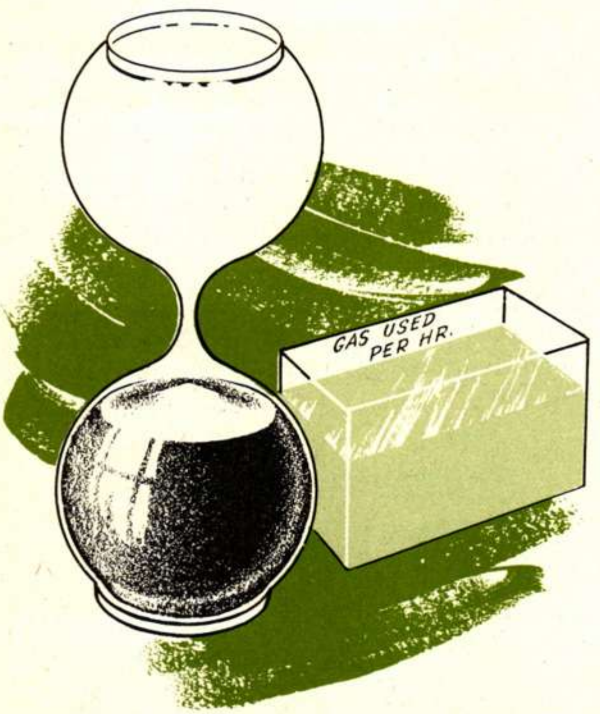
FUEL CONSUMPTION

One of your most important jobs as a navigator is to watch your fuel gage. You must be able to determine at any time during a flight the rate of fuel consumption and the amount of fuel remaining in the tanks. From these two factors you can compute accurately the remaining time the airplane can stay in the air.



In some airplanes the fuel gage shows the number of gallons remaining in the tanks. In others the gage shows the **percentage** remaining. Using either type of gage it is easy to find out how much fuel you have available for the rest of the flight. Subtract this amount from the total amount that was in the tanks when the engines were started to find the number of gallons already consumed.

To find the rate of consumption, USE THE E-6B COMPUTER. Place the number of gallons consumed on the outer scale opposite the number of minutes since the engines were started on the inner scale. Then on the outer scale opposite the black pointer read the rate of fuel consumption, that is, the number of gallons consumed per hour.



Once you know the amount of fuel remaining in the tanks and the rate of consumption, you can find the amount of flying time remaining. On the E-6B computer, set the rate of consumption on the outer scale opposite the black pointer. Then, opposite the number of gallons remaining (on the outer scale), read the time on the inner scale.

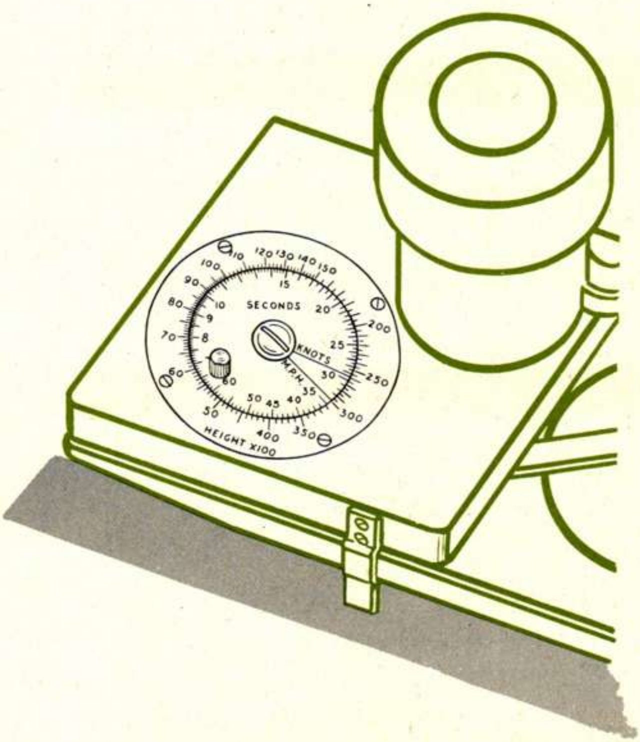
FINDING GROUNDSPEED

TWO QUICK METHODS:

1 GS by Timing, Using B-5 Drift Meter

When you need to compute your GS quickly, you can use the circular computer that is mounted on the B-5 drift meter. This method is much quicker and simpler than taking a double drift or plotting a vector triangle.

Set the drift reading in the drift meter and time the passage of an object from the front to the rear transverse wire. Then, using the circular computer, set this time in seconds on the inside scale opposite the absolute altitude on the outside scale. Then opposite the line labeled "knots" read the groundspeed in knots on the outside scale.



② Bombsight Method

In an emergency, when for any reason you cannot use your drift meter nor take a double drift, you can get a groundspeed from your bombsight. Remember the equation:

$$\text{GS (in mph)} = \frac{\text{DS} \times \text{BA} \times \tan \text{WR}\angle}{7773}$$

$$\text{GS (in knots)} = \text{GS (in mph)} \times 1.15$$

First be sure you have **zero trail**. Then synchronize on some object on the ground and opposite the dropping angle index read the tangent of the whole range angle.

Now multiply BA by disc speed on the computer, and set the result on the outer scale opposite 7773 on the inner scale. Then, opposite the tan WR∠ on the inner scale, read your GS in mph on the outer scale.

HOW TO CONSTRUCT A MERCATOR CHART

Whenever for any reason you do not have a Mercator plotting chart, you can construct one by the method of **graphical construction.** Since the meridians of longitude must be equidistant straight lines, and the parallels of latitude must be non-equidistant straight lines, the only problem is to determine the correct distances between the various parallels of latitude.

Suppose you need a Mercator chart from latitude 40° N to 43° N, and from longitude 75° W to 78° W.

1. Select a convenient longitude scale. A good one for most purposes is: 1° of longitude = 3 inches.

2. Parallel to the lower edge of the sheet, draw a straight line 9 inches long, to allow for 3° of longitude. This line is the base parallel of 40° N.

3. At 3-inch intervals along this line erect perpendicular lines. These are the meridians 75° W to 78° W.

4. At the point where any one of these meridian lines intersects the base parallel, construct an angle of 40°30′ to the base parallel. For example, take the intersection of meridian 75° W with the base parallel. Label this point A. From this point draw a line at an angle of 40°30′ and extend it until it intersects the meridian of 76° W. Label this intersection point B.

5. From point A, swing an arc on a radius of AB until it intersects the meridian of 75° W. Label the point of intersection point C.

6. Through point C, construct a line parallel to the base parallel of 40° N. This line is the parallel 41° N.

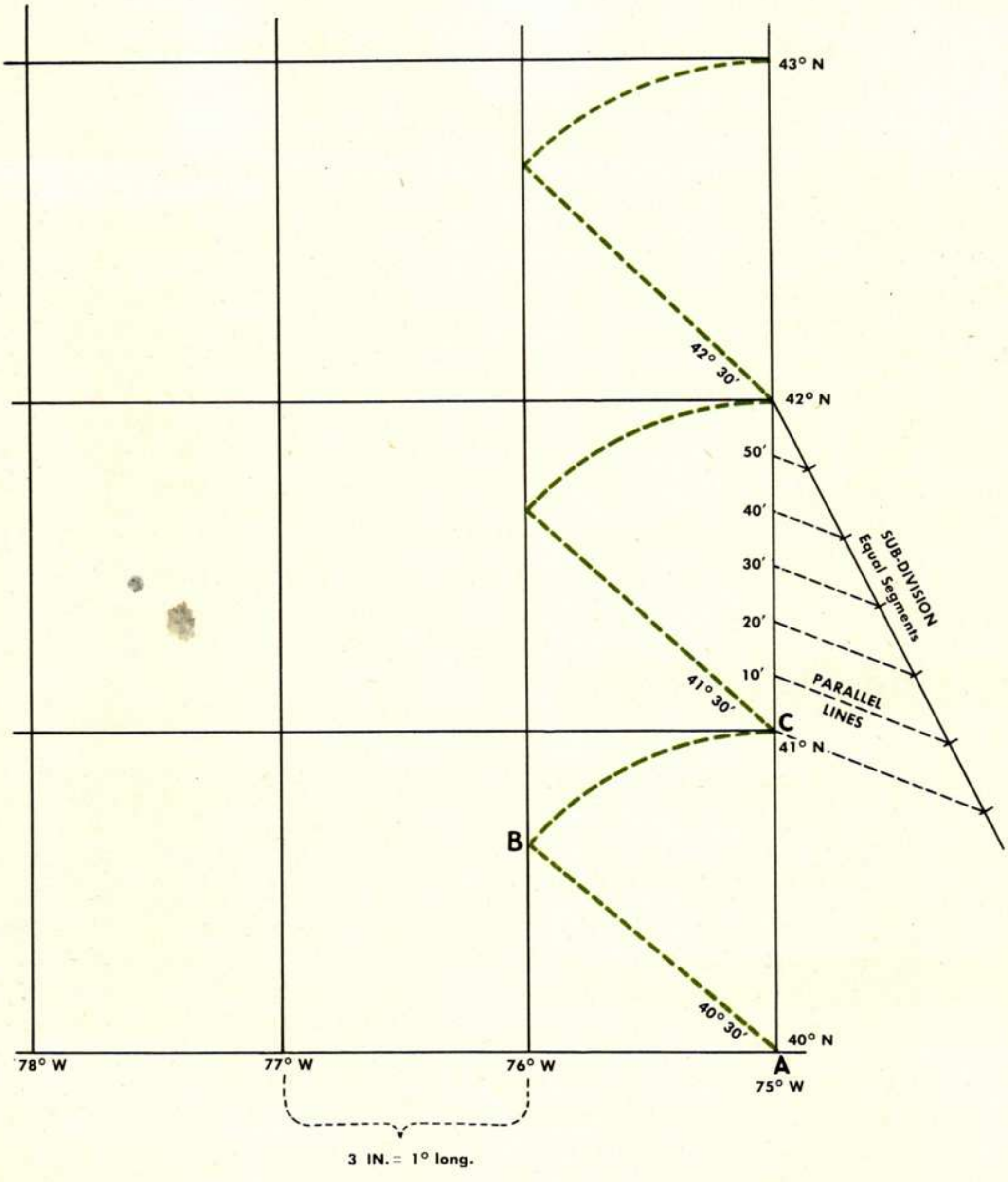
7. At point C, construct an angle of 41°30′ to the parallel of 41° N, and repeat the procedure.

8. Continue in this manner, each time making the angle one-half degree greater than the parallel on which you construct it. By this method, the parallels of latitude will be correctly spaced.

If you need to subdivide the degrees of latitude and longitude into 10-minute intervals, you can do it quickly. From the intersection of any meridian with any parallel, draw a line at any angle. Set your dividers at some convenient short distance, and walk off six steps on this line, marking each step. Draw a line from the end of the sixth step to the next meridian or parallel. From the ends of each of the other steps, construct lines parallel to this line. These lines intersect the parallel or meridian at equal intervals.

This method is not completely accurate, because the 10-minute lines should be non-equidistant, but for all practical purposes it is accurate enough.

MERCATOR CONSTRUCTION



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