DOCUMENT RESUME

ED 111 623 SE 017 460

AUTHOR Cox, Rodney V., Jr.
TITLE Air Navigation. Aerospace Education II.
INSTITUTION Air Univ., Maxwell AFB, Ala. Junior Reserve Office Training Corps.
PUB DATE 73
NOTE 135p.; Colored drawings may not reproduce clearly. For the accompanying Instructor Handbook, see SE 017 461. This is a revised text for ED 068 289

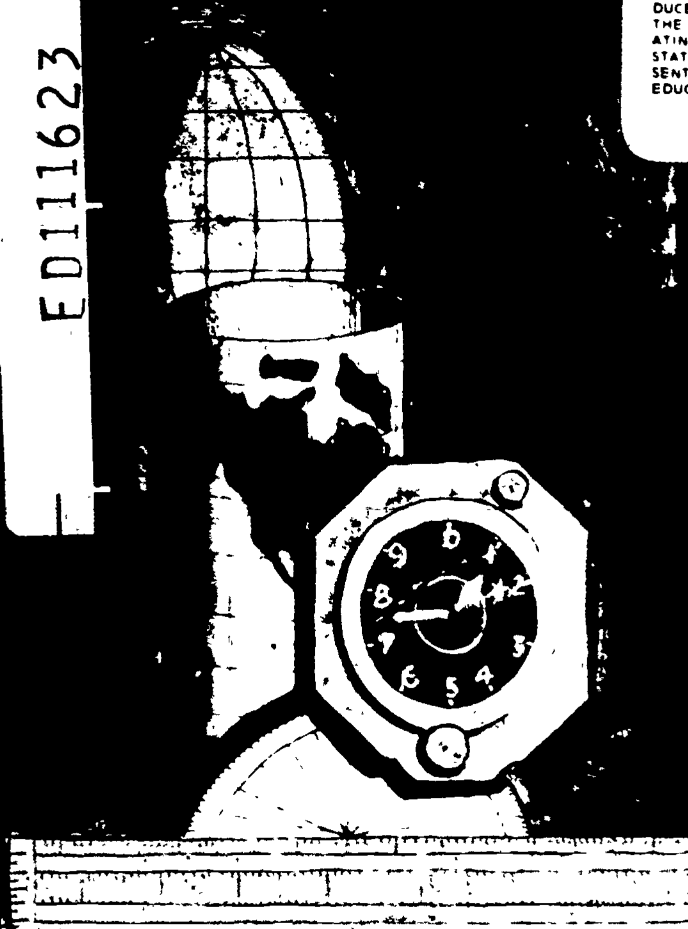
EDRS PRICE MF-$0.76 HC-$6.97 Plus Postage
DESCRIPTORS *Aerospace Education; Aerospace Technology; Aviation Technology; *Instructional Materials; Methods; *Navigation; *Resource Materials; Science Education; Secondary Education; Textbooks
IDENTIFIERS *Air Force Junior ROTC

ABSTRACT

This revised textbook, published for the Air Force ROTC program, contains a discussion of basic and essential understandings about air navigation. The first part of the book describes maps, air navigation charts, flight planning, and pilotage preflight. Basic differences between ground maps and air charts are described and the methods of expressing position, direction, distance, and time are explained. The last three chapters include a description of different types of navigation instruments and aids used in flight. (PS)

ED111623

Aerospace Education II



Junior ROTC / Air University/Maxwell Air Force Base, Alabama

460

AEROSPACE EDUCATION II

Air Navigation

MAJ RODNEY V. COX, JR, *PhD*
Aerospace Education Course Director

AIR FORCE JUNIOR ROTC
AIR UNIVERSITY
MAXWELL AIR FORCE BASE, ALABAMA

1973

This publication has been reviewed and approved by competent personnel of the preparing command in accordance with current directives on doctrine, policy, essentiality, propriety, and quality.

●

This book will not be offered for sale. It is for use only in the AFJROTC program.

●

We gratefully acknowledge the ta[illegible] and contributions of Mr Harley A. Samford, [illegible]oduction Branch, 3825th Academic Services Group, to the development of this and all Aerospace Education texts.

Introduction

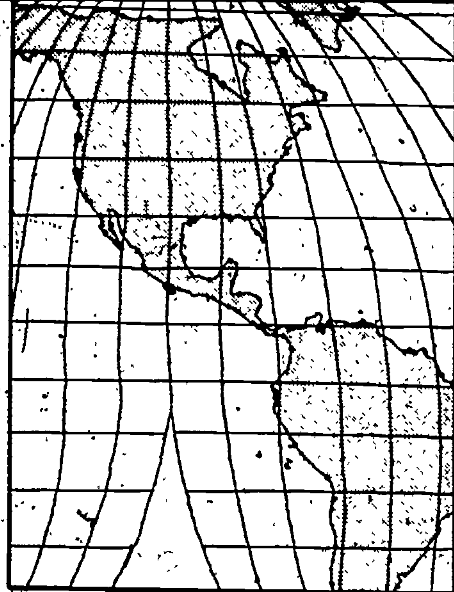
NAVIGATION is the process of directing the movement of a craft from one place to another. The root of the word comes from the Latin word *Navis* meaning ship. Because of this, many have suggested that the term for flying should be "avigation" (avis is bird); however, modern air navigation has little to do with the instinct of a bird, and the same principles of navigation apply to both ships and aircraft. Thus, Air Navigation has become the accepted term.

Air navigation can be defined as "the process of determining the geographical position and of maintaining the desired direction of an aircraft relative to the surface of the earth." Any movement in this universe ultimately involves an intention to proceed to a definite point. Whether you are walking, riding in your car, traveling on shipboard, or flying in an aircraft, navigation is the business of proceeding in such a manner as to arrive at that point. To do this safely is an art. Navigation is considered both an art and a science. It is a scientific art that is at once interesting, fun, exciting, and taxing. There is no more satisfying feeling than flying cross country to arrive over your destination precisely on time and on course. There is nothing more frightening than to be low on fuel at 8,000 feet and not know where you are.

This should be a challenging and fun part of your Aerospace Education course. This text is not designed to make you a professional Air Force navigator. It is designed to give you the rudiments of light aircraft navigation and familiarization with the aids to basic skills.

Contents

APPENDIXES



Chapter 1

From Here to There

THIS CHAPTER introduces you to the basic elements of navigation: time, distance, position, and direction. Also introduced are the elementary concepts of reading maps and their legends. When you have studied this chapter, you should be able to: (1) define the basic elements of navigation, (2) explain the basic parts of the map, and (3) prepare and navigate a point-to-point trip on a road map.

LET'S ASSUME that next Friday is the last day of the school year. Before you start your summer job on Monday, you and several of your friends decide to spend the weekend at the beach.

In our hypothetical situation, you are located in Montgomery, Alabama, and you are going to the beautiful white sands of Fort Walton Beach, Florida. Before proceeding any further, you and your traveling companions decide to go to the local gas station and obtain a map, one of the few free items left on the market. The first thing that you do is to find Montgomery on your map (Fig 1). You now have partially solved the first element of the navigation problem-position. As you look at the location of Montgomery, you see a blob of roads and highways. It is difficult to choose your particular position on this map, and you obtain

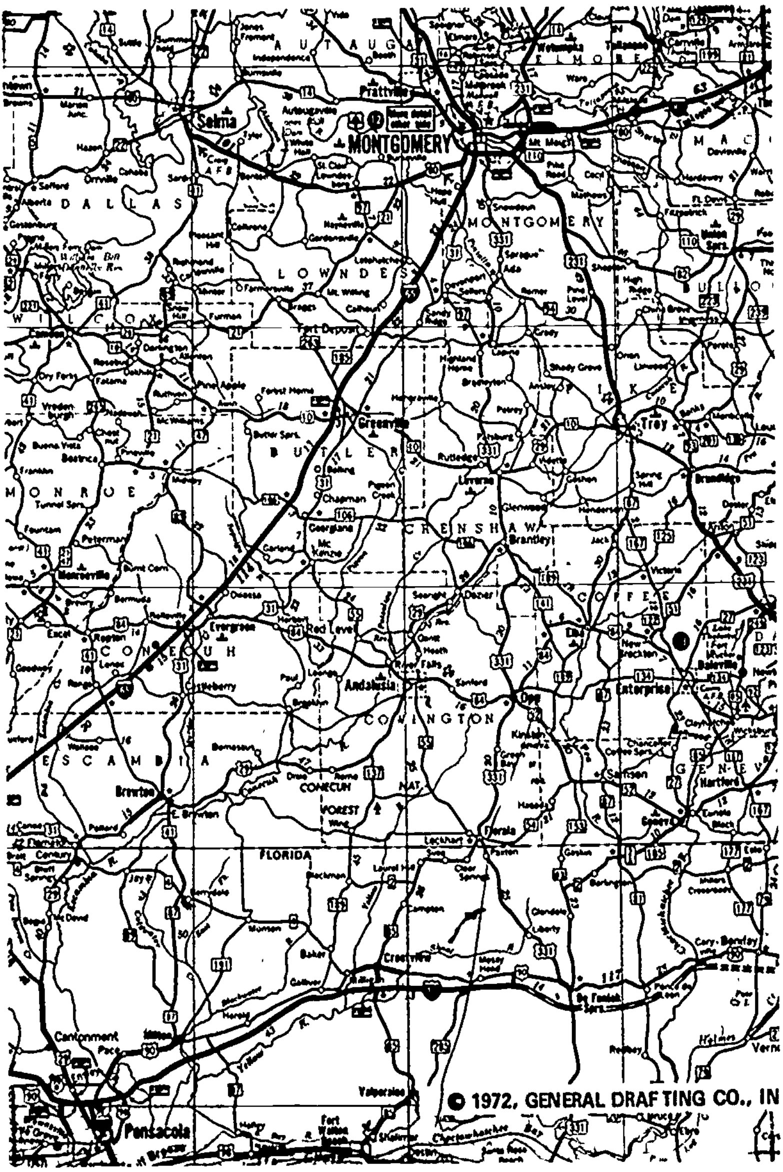


Figure 1. Road Map Section - Montgomery, Alabama to Fort Walton Beach, Florida.

a larger scale city map that gives you more detail (Fig 2). On this map, you locate an exact position where you can begin your navigation to the beaches. This position is the intersection of Norman Bridge Road and South Boulevard. You now have solved the first problem in navigation—starting from a known position.

From the known position, you must decide in which direction you will travel. In traveling by automobile, you are restricted to the highways, a limitation not found in flying. You decide that your general direction will be south. If you were flying, you would figure your heading and fly it. In an automobile, you must select a highway pointing in that general direction. You have now solved the second part of the navigation problem—direction.

School is out at 3:00 pm. Since you have not made the trip before, you must decide whether to leave on Friday or Saturday.

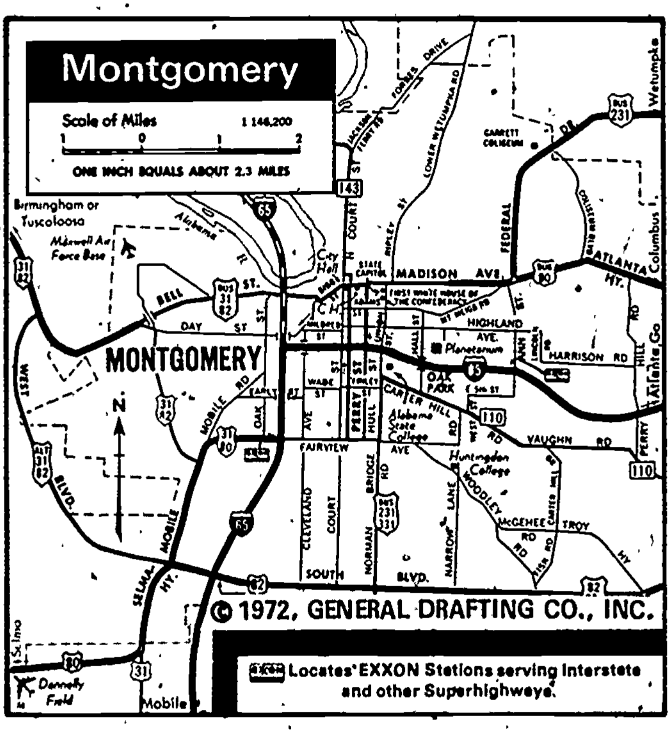


Figure 2. Detailed road map section showing Montgomery, Alabama.

On the map, Route 331 and Route 85 appear to run in the right direction and will take the least time. To verify this, you must check the distance. This is the third element of the navigation problem. Distance is also needed to solve time, the fourth element. To find the distance, you could add up all the little mileages between towns, a tedious chore at best. On the other hand, you could go to the map scale and find how many miles are depicted by an inch on the map (Fig 3) In our example, you find that one inch equals approximately 20 miles. On the map, almost seven inches represent the distance from Montgomery to Fort Walton Beach. Therefore, it is approximately 140 miles. At an average speed of 50 miles per hour (mph), you will take 2 hours and 50 minutes driving time. With stops for gas and eating, you decide that, by leaving after school, you have plenty of time to reach the beach Friday night and find a place to stay, rest after the trip, and, probably most important, find the girls.

You have just completed a pre-trip planning problem. In flying, this is called **preflight** planning. Time taken in pre-planning can save you many headaches on your trip, and, when you are flying, careful, preflight planning can save your life.

Let us review what you have done. After deciding on where you wanted to go, you solved the four problems of navigation:

a. **Position**—In our case, a known point in Montgomery—South Boulevard and Norman Bridge Road.

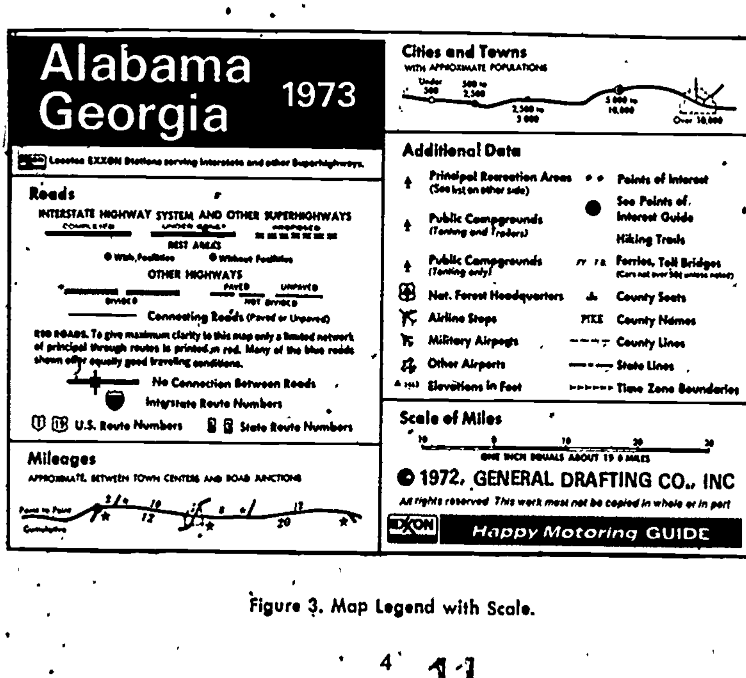


Figure 3. Map Legend with Scale.

b. **Direction**—The beaches lie south of Montgomery; therefore, you picked a highway heading south.

c. **Distance**—Using the map scale, you found the distance to be approximately 140 miles.

d. **Time**—On the basis of safe average speed, you figured that it would take about 2 hours and 50 minutes driving time.

The actual definitions of these elements are:

a. Position is some place that can be identified.

b. Direction is the position of one point in space relative to another without reference to the distance between them.

c. Distance is the space between two points and is measured by the length of a line joining them.

d. Time is either the hour of the day or an elapsed interval.

MAP ELEMENTS

Thus far, you have used the road map to find such items as position, distance scale, and road direction. Actually, this map can give a lot more information designed to help ease your trip. By reading the map, you can greatly reduce your chances of getting lost or having trouble.

Every map has a **legend** which is a key to explain the meaning of the symbols on the map. Our legend (Fig 3) included the miles scale that you used to measure the distance.

Let's take a closer look at the legend. You can tell whether the highways that you have selected are paved. You can see if the highway is finished or being constructed or if it is only a proposed route. You selected Routes 331 and 85. Are these highways paved? Are they divided highways? Are they interstates?

You can also see in the legend that the map will give the approximate sizes of the towns and cities that you will travel through. What is the approximate population of Opp, Alabama? How about Florala?

Additional data is shown on our map, such as the location of airports, campgrounds, and county lines. Also shown are highway route numbers and towns that are county seats. After leaving Montgomery, you pass through one more Alabama county seat. What is it?

You used the mileage scale to find distance. Distances between individual points along the highways are marked off on this map by little stars, with the mileage noted in numbers about halfway between the stars. On other maps, the markers might be dots or checks. How far is it between Luverne, Alabama, and Brantley, Alabama? Would it be shorter to take Routes 141 and 84 than Route 331 between Brantley, Alabama, and Opp, Alabama? How many miles shorter or longer is it?

This map shows only a few of the symbols that can be depicted. Relief, cultural, and hydrographic features are three items among the many that are shown on maps.

Relief features, which are physical features as related to the height of the land surface, can be shown. These include mountains, hills, plateaus, plains, valleys, etc. Relief features are shown by various methods, such as shading, contour lines, spot elevations, and variations in color.

A **contour** is a line connecting points of equal elevation. Figure 4 shows the relationship between contour lines and terrain. Notice that, on steep slopes, the contours are close together and, on gentle slopes, they are farther apart.

A spot elevation is the height of a particular point of terrain above sea level. This is usually denoted by a number next to a dot, and it indicates the height above sea level.

Different colors are used to designate areas of different elevation. These are called **gradient tints.** Shading or darkening as the height increases is a version of gradient tint.

We have already seen how many man-made features are depicted on maps. These are known as **cultural features.** Populated

Figure 4. Contour Lines.

places, roads, railroads, installations, dams, and bridges are some of the many kinds of cultural features portrayed. Standardized coded symbols denoting cultural features are usually keyed in a map legend. However, some maps use pictorial symbols, which are self-explanatory and require no explanations in the legend. Just north of Andalusia, Alabama, (Fig 1) is a cultural feature not explained in the legend. What is it?

Hydrographic features, such as oceans, coast lines, lakes, rivers, streams, swamps, and reefs, are portrayed by either tinting or blank spaces on the map. Some maps show vegetation, such as park areas, orchards, hedgerows, and vineyards. The maps that do portray vegetation are usually more detailed than is necessary for our use.

Almost anything can be portrayed on a map in one way or another. Such things as highway route numbers are very valuable for a road map, but they are not very useful for someone navigating an aircraft at 6,000 feet. Maps have many different purposes. If one tried to show everything on one map that would be useful for everyone, the map would be so cluttered that it would be unreadable.

WORDS AND PHRASES TO REMEMBER

preflight
position
direction
distance
time

legend
relief features
contour
gradient tints
cultural features
hydrographic features

QUESTIONS

1. To get more detail, we use a map with a larger/smaller scale?
2. The one element of navigation that is needed before any others can be found is ______________________________.
3. The ______________________________ is the navigation element that deals with the relative position of two points without regard to distance.
4. The separation between two points is the ____________________ between these points.
5. To find the navigation element time, you need to know the ____________ ______________________________ navigation element.

6. The elapsed interval to travel between two points is called ________________________________.

7. On every map, the key that explains the symbol is called the ________________________________.

8. Using Figures 1, 2, and 3, answer the following questions:
   a. Norman Bridge Road in Montgomery is also known as Route ________ and Business Route ________.
   b. If you travel 22 miles south on Route 31 from Montgomery, you will be located at ________________________.
   c. The airfield at Andalusia, Alabama, is a military airfield. (True or False).

9. The depiction of height of the land surface is shown by ________________ ____________ features.

10. Three ways to depict land surface height are:
    a.
    b.
    c.

11. A lake is an example of a ________________________________ feature on a map.

THINGS TO DO

1. Go to your local gas station and get a map of your area. Plan a trip from your home to some point at least 150 miles away. Use the four elements of navigation to plan the shortest route. Pick out all cultural, relief, and hydrographic features 10 miles on either side of your route and identify them.

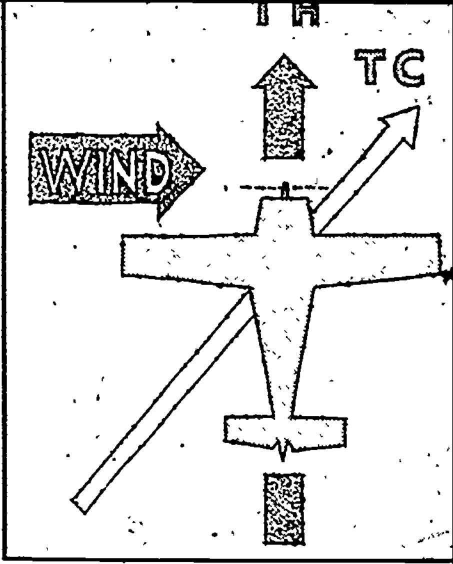
2. Get a group of students together and plan a car navigation rally. Choose a route and write directions for each car to follow. Set an average speed to be maintained (well below the speed limit); set up check points and deduct points for missing the estimated time of arrival at each point. From the map, pick out features along the route and ask the contestants to answer questions about them. The contestant or team of contestants (driver and navigator) who lose the fewest points win.

SUGGESTIONS FOR FURTHER READINGS

US Air Force AFM 51-40, *Air Navigation*, Vol 1, Washington, DC: Department of the Air Force, 1968.

LYON, THOBURN C., *Practical Air Navigation*, Denver, Colorado: Jeppeson, 1972.

SANDERSON, *Aviation Fundamentals*, Denver, Colorado. Sanderson, 1972.



Chapter 2

From Here to There in the Air

THE DIFFERENCES between navigating on the highways and in the air are studied in this chapter. Upon completion of this chapter, you should be able to: (1) explain the differences between ground maps and air charts; (2) identify the symbols on an air chart; (3) understand the use of different scale maps for navigation; (4) understand the basics of pilotage; and (5) understand procedures to be followed if you are lost.

SUPPOSE that, instead of driving to the Florida beaches from Montgomery, you or one of your friends has his private pilot's license, and you decide to fly to the Talladega International Speedway to see the 500-mile stock car race. The Maxwell AFB Aero Club has an airplane available for the weekend, and your friend, the pilot, is eligible to use it.

The first step is to find the proper map. The road map that you used to drive to Florida was designed for driving. Information on county seats, gas stations, and points of interest is not very valuable when you are flying at 6,000 feet. On the other hand, some very valuable information for air navigation, such as location of railroads, radio aids, and tall towers are not depicted on a road map. What you need now is a map designed specifically for air navigation.

If you asked someone for an air navigation map, you would probably face a barrage of questions because there are many different kinds of air navigation maps. Each is designed for a particular method of navigation. Although the words "charts" and "map" may be used interchangeably, most professional navigators, whether on land or sea, refer to maps as charts. For your trip, you need a chart that will show enough features for you to navigate to your destination.

AIR NAVIGATION CHARTS

The pilot of a light aircraft navigates primarily by landmarks and needs a chart emphasizing the landmarks easily identifiable from the air. The airline pilot, on the other hand, is usually only near enough to the ground to navigate by landmarks on takeoff and landing. It should be noted here that every flight entails some landmark flying even if it is only to determine that the pilot will land on the proper runway. For navigation purposes then, the light plane and the airline pilot need different kinds of charts.

The type of navigation chart needed depends on the mission to be flown. Some of the most common charts in use today include sectional charts, operational navigation charts, and jet navigation charts. These charts are designed primarily for landmark flying.

The primary difference in these charts is their scale. Obviously, charts are much smaller than the area which they represent. The ratio between any given unit of length on a chart and the true distance that it represents on the earth is the scale of the chart. If a chart is to show the whole world and still not be too large, it must be drawn to a small scale. To show much detail, such as that needed for the trip from Maxwell AFB to Talladega, the chart must be drawn to a large scale. Because of the larger scale, a smaller area is covered by the same size chart as one with a smaller scale. Remember. large area, small scale, small area, large scale.

The scale of a chart may be given by a simple statement, such as, "one inch equals ten miles." This means that a distance of 10 miles on the earth's surface is shown as one inch on the chart.

The scale may also be given as a representative fraction, such as 1:500,000 or 1/500,000. This means that one of any unit on the chart represents 500,000 of the same unit on the earth. For example, one inch on the chart represents 500,000 inches on the earth.

A representative fraction can be converted into a statement of miles to the inch. Thus, if the scale is 1:1,000,000 or 1,000,000 divided by (6080 × 12), one inch equals 13.7 nautical miles. On a chart with a scale 1:500,000, one inch on the chart represents 6.85 nautical miles. The larger the denominator of the representative fraction the smaller the scale.

One other means of showing scale is the **graphic scale.** This is a graduated line usually printed along the border of a chart. Take a measurement on the chart and compare it with the graphic scale of miles. The number of miles that the measurement represents on the earth may be read directly from the graphic scale on the chart.

The **Jet Navigation (JN) Chart** has a scale of 1:2,000,000. The chart shows many pertinent hydrographic and cultural features. It is designed for planning and navigation for flights by long-range, high-speed aircraft. The detail primarily emphasizes features that a navigator can identify from a high altitude. A map that shows more detail of hydrographic and cultural features is the **Operational Navigation Chart (ONC).** The ONC scale of 1:1,000,000 is larger than the JN and, therefore, usually does not cover as large an area on a single chart. The ONC is used for medium- and some low-level navigation for flights by higher speed aircraft.

The sectional chart, which you will use on your flight, is considered the basic aeronautical chart of the United States. The sectional chart scale is 1:500,000 and has the largest scale of the three basic aeronautical charts used for landmark flying.

The **Sectional Aeronautical Chart** provides detailed ground features that are good for visual ground/chart orientation at predetermined checkpoints. This type of chart shows many types of hydrographic and cultural features. It also depicts all important navigation aids and air facilities.

Parts of Charts

We have looked at the three types of charts, and, for your flight, we have decided to use the sectional. The sectional charts are produced by the National Oceanic and Atmospheric Administration in Washington, DC. They can be bought at almost every airport. Since each sectional chart can cover only a relatively small area, we must find which sectional to choose. Figure 5 shows the sectional charts that cover the United States. This index is shown on every sectional chart. Apparently, the chart that you will need is the Atlanta Sectional.

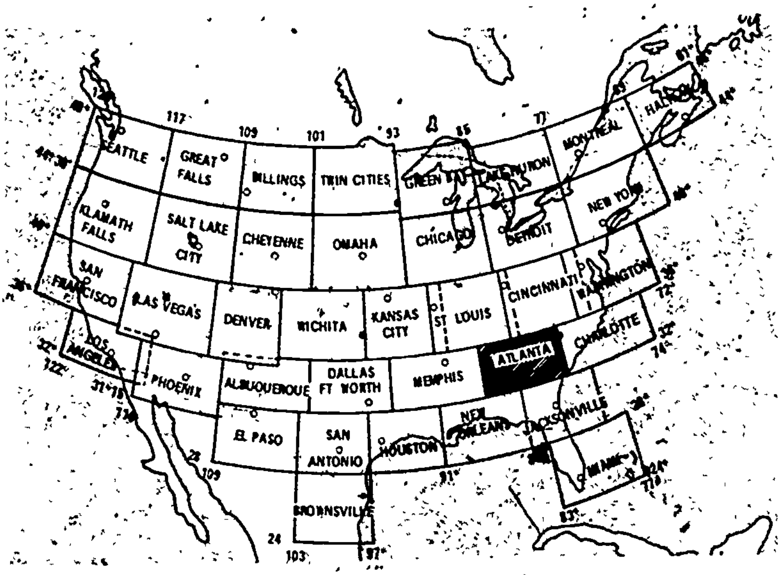


Figure 5. Index of Sectional Charts covering the United States.

Let us take a closer look at our sectional chart. The first thing that you should look for is the title information (Fig 6).

Note that we have the Atlanta Sectional Chart with a scale of 1:500,000. It is a Lambert Conformal Conic Projection: we will study what this means later. The next section is probably the most important on the chart. You must check to insure that your chart is not outdated. As you can see, this chart should have become obsolete for use on 27 April 1972. Do not use an obsolete chart

SOUTH

NORTH

ATLANTA

SECTIONAL AERONAUTICAL CHART

SCALE 1:500,000

Lambert Conformal Conic Projection-Standard Parallels 33°20' and 38°40'

Topographic data corrected to August 1971

7TH EDITION corrected to include airspace amendments effective October 14, 1971
and all other aeronautical data received by September 13, 1971

Consult appropriate NOTAMS and Flight Information
Publications for supplemental data and current information

This chart will become OBSOLETE FOR USE IN NAVIGATION upon publication of
the next edition scheduled for APRIL 27, 1972

PUBLISHED IN ACCORDANCE WITH INTER-AGENCY AIR CARTOGRAPHIC COMMITTEE
SPECIFICATIONS AND AGREEMENTS APPROVED BY

DEPARTMENT OF DEFENSE FEDERAL AVIATION ADMINISTRATION DEPARTMENT OF COMMERCE

Figure 6. Sectional Chart Title Information.

for flying!!! Running into a new tower not plotted on an old chart can ruin your whole day.

Figure 7 shows the relief features depicted on our chart. The tint shading on the right side is made up of different colors. There is pale green at sea level; dark green from 1,000 to 2,000 feet; pale yellow from 2,000 to 3,000 feet, dark yellow from 3,000 to 5,000 feet; and salmon colored from 5,000 to the highest elevation depicted on this chart (6,684 feet).

The aeronautical symbols on our sectional chart are depicted in Figure 8. What does a little parachute mean? What symbol shows an airfield with a runway over 1,500 feet long with no facilities? What does the number in parentheses beside a tower or obstruction mean?

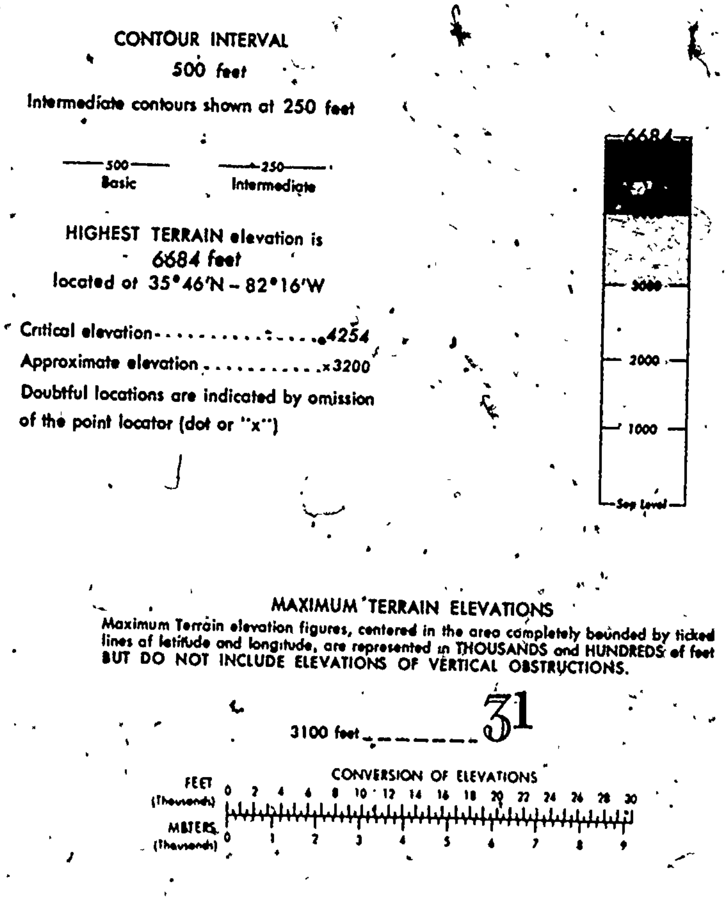
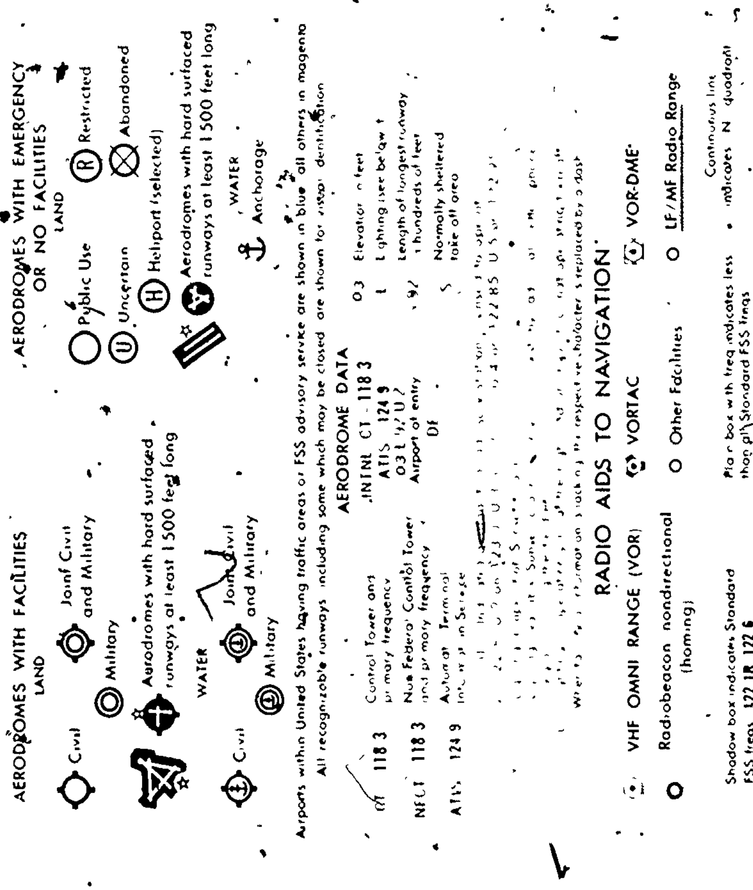
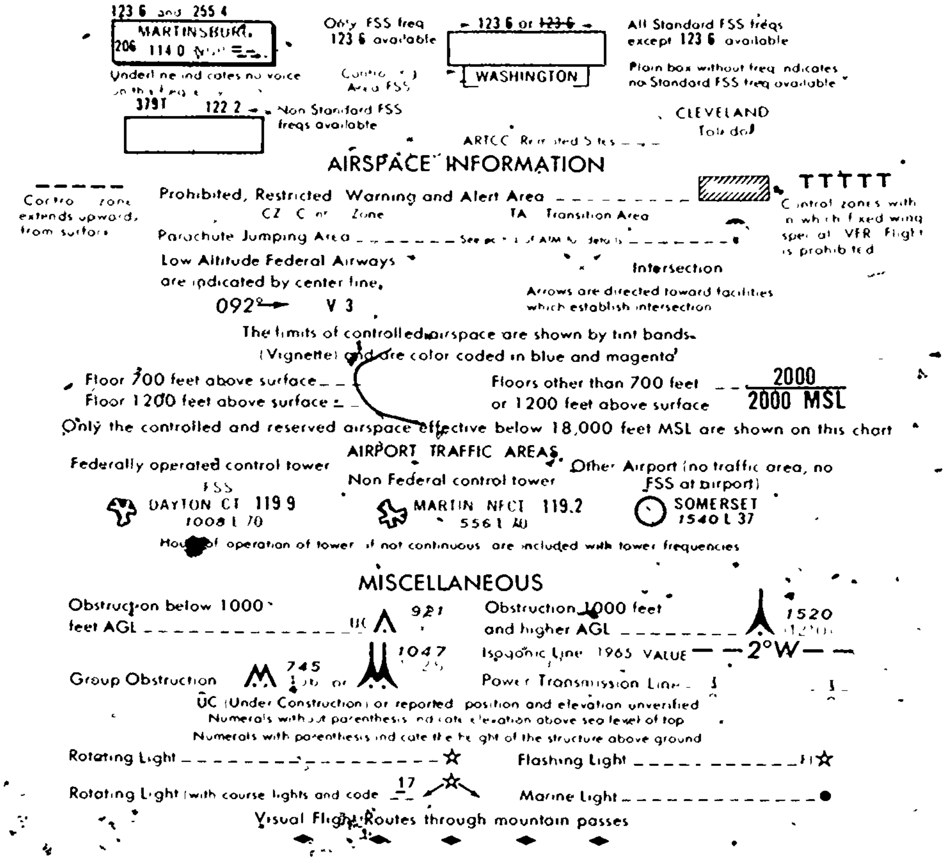


Figure 7. Relief Features.

Aeronautical Symbols

Figure 8.




123 6 and 255 4
MARTINSBURG
206 114 0
Underline indicates no voice on this freq
379T 122 2
Non Standard FSS freqs available
Only FSS freq 123 6 available
Control Area FSS
123 6 or 123 6
WASHINGTON
All Standard FSS freqs except 123 6 available
Plain box without freq indicates no Standard FSS freq available
CLEVELAND
ARTCC Remoted Sites
AIRSPACE INFORMATION
Control zone extends upward from surface
Prohibited, Restricted Warning and Alert Area
CZ Control Zone
TA Transition Area
Parachute Jumping Area
Control zones within which fixed wing special VFR Flight is prohibited
Low Altitude Federal Airways are indicated by center line,
092° V 3
Intersection
Arrows are directed toward facilities which establish intersection
The limits of controlled airspace are shown by tint bands (Vignette) and are color coded in blue and magenta
Floor 700 feet above surface
Floor 1200 feet above surface
Floors other than 700 feet or 1200 feet above surface
2000
2000 MSL
Only the controlled and reserved airspace effective below 18,000 feet MSL are shown on this chart
AIRPORT TRAFFIC AREAS
Federally operated control tower
FSS
DAYTON CT 119 9
1008 L 70
Non Federal control tower
MARTIN NFCT 119.2
556 L 40
Other Airport (no traffic area, no FSS at airport)
SOMERSET
1540 L 37
Hours of operation of tower if not continuous are included with tower frequencies
MISCELLANEOUS
Obstruction below 1000 feet AGL
UC
921
Obstruction 1000 feet and higher AGL
1520
1047
745
Group Obstruction
Isogonic Line 1965 VALUE
2°W
Power Transmission Line
UC (Under Construction) or reported position and elevation unverified
Numerals without parenthesis indicate elevation above sea level of top
Numerals with parenthesis indicate the height of the structure above ground
Rotating Light
Flashing Light
Rotating Light (with course lights and code
17
Marine Light
Visual Flight Routes through mountain passes

Thus far, we have found the title information, relief data, and aeronautical symbols used on our chart. With the other data arranged around the edge of the chart, these constitute the legend of this chart.

One of the more important items found in the margin of the chart is the list of prohibited, restricted, warning, and alert areas that are included on the chart (Fig 9). This list explains restrictions that apply in a particular area and who is responsible for the area. Also found here is an explanation of what is a prohibited, restricted, or alert area. Are you permitted to fly into a prohibited area? What are the restrictions for an alert area? If I wanted to fly through R-2102, whom would I contact for permission?

Much more information is included in the margin of your chart, such as the graphic scale, special notices, remote control frequencies for radio contacts, and control tower frequencies. This information could be useful, and you should be familiar with each of these items.

PROHIBITED, RESTRICTED, WARNING, AND ALERT AREAS ON ATLANTA SECTIONAL CHART

NO.	NAME	ALTITUDE	TIME	APPROPRIATE AUTHORITY
R-2101	Anniston Army Depot, Ala.	To 5000	0700 to 1800 Mon. thru Sat.	C. O. Anniston Army Depot
R-2102	Fort McClellan, Ala.	Subarea A - To 8000 Subarea B - From 8000 to & including 14,000 Subarea C - From 14,000 to FL 240	Continuous	† FAA, Atlanta ARTC Center or area FSS. C. O. Fort McClellan, Ala.
R-2104A	Huntsville, Ala.	To FL 300	Continuous	† FAA, Memphis ARTC Center or area FSS. C.G., U.S. Army Missile Command, Redstone Arsenal, Ala.
R-2104B	Huntsville, Ala.	To 2400	Continuous	† FAA, Memphis ARTC Center or area FSS. C.G. U.S. Army Missile Command, Redstone Arsenal, Ala.
A-301A	Savannah, Ga.	To 4000 MSL excluding 2 NM either side Allendale, S.C. VOR 175°M rad extending from Savannah CZ to 32°21'N. Alert Corridor floors shown on chart.	0600 to 2400 Mon. thru Fri.	Commanding Gen. U.S. Army Flight Training Center, Ft. Stewart, Ga.
A-301B	Savannah, Ga.	To 1500 MSL	0600 to 2400 Mon. thru Fri.	Commanding Gen. U.S. Army Flight Training Center, Ft. Stewart, Ga.

P - Prohibited R - Restricted W - Warning A - Alert † - Controlling Agency

Unless otherwise noted: Altitudes are MSL and in feet; time is local.

No person shall operate an aircraft within a Prohibited Area, or within a Restricted Area between the designated altitudes during the time of designation unless prior permission has been issued by the appropriate authority as listed above. The appropriate authority is defined as either the controlling agency (†) or the using agency.

Flight within Alert Areas is not restricted, but pilots are advised to exercise extreme caution. 8-26-71

Figure 9. Prohibited, Restricted, Warning, and Alert Areas.

As you study our map more closely, you notice that the upper half of the area is printed on one side, and the lower half of the area is printed on the other side.

FLIGHT PLANNING

We have selected the sectional chart because it gives enough details of points on the ground so that we can use them in navigating from Maxwell AFB to Talladega. This type of landmark flying is called **pilotage.** In the United States, as long as the weather is good, it is possible to fly almost anywhere by pilotage. Other means of navigation are explained later, but the basic method of light plane navigation is pilotage.

Whether the flight is enjoyable depends a great deal on how well you preplan or preflight. Preflight activities include not only planning the flight but also making a check of your aircraft. Here, we are primarily concerned with the preplanning of your flight.

The next step after selecting your chart is to check the **Airman's Information Manual (AIM).** The AIM is divided into four parts and a supplement. Each part of the AIM contains information vital to the planning of your flight.

Part 1 contains textbook type material; such as a Glossary of Aeronautical Terms, Emergency Procedures, and Health and Medical Facts of interest to flyers. This part is revised and issued every three months.

Part 2 of the AIM is the Airport Directory and is a listing of flight service station and weather bureau telephone numbers. Part 2 is revised and issued semiannually.

Part 3 contains Operational Data and Notices to Airmen. This part is issued every 28 days. The **Notices to Airmen (NOTAMS)** section, which is a supplement to Part 3, includes items considered essential to the safety of flight. This supplement is published every 14 days.

Part 4 of the AIM is entitled "Graphic Notices and Supplemental Data." It contains a list of abbreviations used in AIM and other items, such as Heavy Wagon and Oil Burner Routes (high-speed low-level navigation training routes for Air Force bombers and fighters). This part is revised semiannually.

For your flight, you need to check Part 2 closely for information about your destination airfield Talladega, and you also need to find the telephone number of the nearest weather station. In Part 3, you should take a look at the NOTAMS to insure that none of these affect you. On every flight, parts of the AIM should be checked, and the flyer should be at least familiar with all parts of AIM.

After selecting your chart and checking the AIM, you should check the weather for current reports, forecasts for enroute and destination weather, winds at flying altitude, and **pilot weather reports (PIREPS).** This can be done by telephone, but a visit to the weather station at an airport is preferable.

On your flight, you will navigate by pilotage or landmark flying. This, of course, means that you will need to maintain visual contact with the ground at all times. This type of flying is considered to be under **visual flight rules (VFR).** If you were making your flight in weather, you would fly under **instrument flight rules (IFR).** Whenever you fly IFR, you must file a flight plan with a Federal Aviation Administration (FAA) flight service station (FSS). An FSS is an air-ground voice communication station that relays clearances, requests for clearances, and position reports between enroute aircraft and traffic control centers. In general, the FSS is a facility that aids the flyer during all phases of the flight. For VFR flights, you are not required to file a flight plan, but it is a good idea to do so anyway. Figure 10 shows the flight plan for your proposed flight. With a filed flight plan, everyone knows your intentions, and, if something happens, the proper agencies

DEPARTMENT OF TRANSPORTATION—FEDERAL AVIATION ADMINISTRATION
FLIGHT PLAN
Form Approved
OMB No. 04-R0072

1 TYPE	2 AIRCRAFT IDENTIFICATION	3 AIRCRAFT TYPE/ SPECIAL EQUIPMENT	4 TRUE AIRSPEED	5 DEPARTURE POINT	6 DEPARTURE TIME PROPOSED (Z)	6 DEPARTURE TIME ACTUAL (Z)	7 CRUISING ALTITUDE
✓ VFR / IFR / DVFR	B4633A	CESSNA 172	120 MPH KTS	MXF	1000		5500

8 ROUTE OF FLIGHT: Dir Talladega Apt

9 DESTINATION (Name of airport and city)	10 EST. TIME ENROUTE HOURS	10 EST. TIME ENROUTE MINUTES	11 REMARKS
Talladega Apt. Talladega, Ala.	0	50	–

12 FUEL ON BOARD HOURS	12 FUEL ON BOARD MINUTES	13 ALTERNATE AIRPORT (S)	14 PILOT'S NAME, ADDRESS & TELEPHONE NUMBER & AIRCRAFT HOME BASE	15 NUMBER ABOARD
4	30	NR	J.M. HERNANDEZ 718 Edgemont Ave Montgomery, Ala. 265-0007 MAXWELL AFB, Ala	4

16. COLOR OF AIRCRAFT	
Blue White Trim	CLOSE VFR FLIGHT PLAN WITH Anniston FSS ON ARRIVAL

FAA Form 7233-1 (5-72)

Figure 10. Flight Plan.

will have the information that they need. For example, if you are overdue at your destination, search procedures can be started.

In explaining every little detail, we make it appear that a great deal of work is associated with preplanning a flight. In reality, after a few flights, you will develop a routine, and almost everything explained so far can be done in a few minutes. These few minutes can save a lot of grief and maybe even your life.

Everything discussed so far is done on every flight. The next few steps of flight planning are concerned primarily with your method of navigation-pilotage. If you were planning to fly IFR by radio navigation, you would flight plan differently.

PILOTAGE PREFLIGHT

You have checked the weather and found it to be "good" between Maxwell AFB and Talladega, and it is forecast to remain so. In checking the AIM, you find that the airfields are okay and will be open for your flight.

The next thing is to plan your route of flight in detail. This includes the four elements of navigation: position, direction, distance, and time.

Taking your up-to-date chart, the first thing is to locate your departure and destination points (Fig 11). This gives the first element of the navigation problem-position. Maxwell AFB just outside of Montgomery, Alabama, is your known starting point. Talladega Airport is located northeast of Montgomery. After locating these two points, you should have drawn a line between them whether you intend to fly the straight-line route or not.

To prepare the chart for easy reference and to figure their distance, most pilots mark the line in 10-mile increments. This can be done by laying a piece of paper along the statute mile line of the graphic scale and marking 10-mile increments along the edge of the paper. Next, lay the paper along the route and transfer the 10-mile marks to it. Many navigators mark each increment with the mileage; others indicate the 50-mile mark by making it longer than the 10-mile marker. Your straight-line route is 84 miles long. You have solved the distance element of your navigation problem if you decide to fly the straight-line route.

Your aircraft cruises at 120 mph or 2 miles per minute. The time enroute for a straight-line flight is 42 minutes ($84 \div 2$).

On your straight-line course, you see that your direction is approximately northeast. While you are looking at the straight-line route, take a minute and study it. Is it the safest route? Does it make you fly over high terrain or over wide bodies of water?

Figure 11. Sectional Chart for Flight from Maxwell Air Force Base to Talladega Airport

Are there emergency airports that you can use in case of aircraft malfunction or a thunderstorm? Also, are there plenty of landmarks along the route so that there is no chance of getting lost? When navigating by pilotage, you should always have an alternate route that will help to insure an easy and safe flight.

When you look for alternate routes, you should remember that, since this chart is designed specifically for flying, it omits some items which might hide significant navigation points. On the other hand, some features are shown out of proportion because of their navigational value. For instance, on your proposed flight to the races, the destination, Talladega airport, is shown as being over two miles square in size. In reality, it has a 6,000 ft runway, and it is a mile long narrow complex. From the air, however, it stands out as a good navigation point, and it is, therefore, emphasized on the chart.

After studying the chart, you decide that the straight-line route does not appear to be the easiest or the safest. You note that after crossing Lake Jordan 20 miles out of Maxwell, you will not have many good checkpoints or landmarks for 30 miles. Also, there are only a few emergency airfields in this area.

You decide to follow the straight-line route for approximately 19 miles to Lake Jordan and then turn left to follow the Coosa River and the power line to the airport, dam, converging power lines, and power plant just north of Ware Island. From there, you will turn right, following the power line for 12 miles until you pick up the railroad, road, and powerline running into Sylacauga. After crossing the town, you will pick up the road, railroad, and powerline running northeast to Talladega. From there, you can fly north until you see the destination airfield next to the racetrack.

Overall, this route appears to be the safest. It has emergency airfields along the route and plenty of landmarks to navigate by. With the exception of the short distance between Ware Island and Fayetteville, you are not depending on only one linear feature to follow. A **linear feature** is a straight road, railroad, power line, etc, which can be followed. When you pick only one, especially a road, it is very easy to pick the wrong one and become lost. The best method is to find two linear landmarks running in your direction so that you can make a crosscheck. Also, you need distinct features crossing the route so that you can check your time to see how fast you really are moving across the ground.

The Federal Aviation Administration (FAA) produces **VFR Pilot Exam-O-Grams,** which are brief and timely explanations of important aeronautical items. In VFR Exam-O-Gram No 18 is some very good advice for your flight:

"Remember this point. Be sure you have up-to-date charts, including those adjacent to the one in use. Everything which appears on the chart will usually be on the ground, but no standard chart is so detailed that everything you can see on the ground can also be found on the chart."

When you mark off 10-mile distances on the new route, you see that the total is 94 miles. By taking a safer and easier route, you have added only 10 miles to your distance. At 120 mph, this amounts to a total of 5 minutes more flying time, a small price to pay for safety and peace of mind.

When you checked the weather, you found that the winds at your flight altitude are light and variable, therefore, your cruising speed of 120 mph will also be your speed over the ground. Thus, at 2 miles per minute, you will take approximately 47 minutes flying time to reach your destination. You actually need to add about 2 or 3 minutes to allow for time to climb and reach cruising speed. On your flight plan, under Estimated Time Enroute, you insert 0 hours 50 minutes. This completes your preflight planning.

You have checked the weather and AIM, filed your flight plan, and studied your route. You can now proceed to the aircraft and perform the preflight checks on it. After strapping in, starting the engine, and taxiing to the end of the runway, you ask over the radio for take off clearance. You are cleared and ready for takeoff.

THE FLIGHT

Takeoff from Maxwell AFB was made on Runway 36, meaning that you took off going due north. As you start your takeoff roll, you notice the time. It is 1000 (10.00 am); you only need to turn a few degrees right to be on course.

You climb to your designated altitude of 5,500 ft with the local altimeter setting set in your altimeter. You chose this altitude because your first heading was made in the eastern hemisphere of altitude separation (Fig 12). After making your first turn over Lake Jordan, you will be heading toward the western hemisphere, and you must either climb to 6,500 ft or drop of 4,500 ft.

At 1008, you pass over the Wetumpka Airport, which is located at your 10-mile mark and should be just to your left. In quick succession, you spot the little town of Elmore with its distinctive junction of railroads, immediately followed a little further to the left by the small lake and prison. Just beyond this point, you see

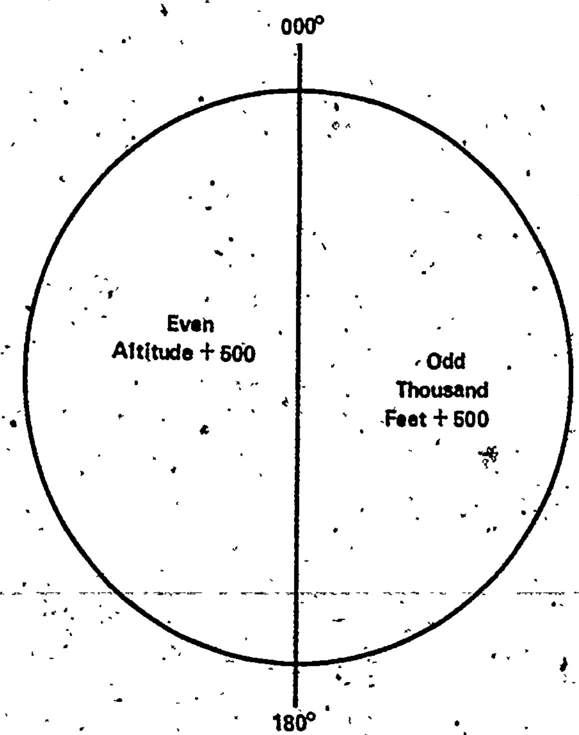


Figure 12. Hemispheric Altitude Separation - Based on aircraft heading.

Lake Jordan, and you cross-check your position using the dam to your right and the converging power lines.

As you cross the shore of the lake, you turn left and notice the two distinctive lake inlets, one on either side as you come up on the 20-mile mark. The time is 1013 or 13 minutes into your flight. You had planned to fly 120 mph, which should have you at 20 miles in 10 minutes plus 3 minutes for takeoff (TO) and climb. You are right on schedule.

You fly to one side of the river out of Lake Jordan to pick out landmarks, such as the distinctive curve just short of the 30-mile mark and the bridge, dam, power plant, and tower at about 33 miles. You note your time when you pass the dam, and it is 1021. You should have reached this point in 19½ minutes (16½ + 3 for TO and climb). You decide that some wind must be slowing the aircraft, since it appears that you are behind your flight plan by 1½ minutes. No sweat!!

The camp at about 36 miles is not visible from the air, but you don't worry, since the wide lake finger to your right is very distinct. At approximately 42 miles, you spot the river island and then the second island with Ware Island Airport on it. These are followed by your turning point, the dam and power plant.

You make the turn at 1027. Your planned time was approximately 1024½- still no cause for worry. Since this leg has few check points, you need to be very careful. You pick out the power line running northeast, and, crossing the finger of the lake, you start to follow the power line. Here you are violating a basic principle of pilotage: don't follow only one landmark. Only a short distance further, you spot Fayetteville and the railroad running into Sylacauga. In case you had missed this checkpoint, you had planned to fly until you crossed Route 280, a divided four-lane highway, and then turn right back to Sylacauga. However, since you have spotted Sylacauga and Lee Merkle Airport along the highway, you don't need to use this alternative.

Turning over Sylacauga, you easily sight and follow the railroad, road, and powerline running northeast. At Sycamore, an excellent checkpoint with all your landmarks converging, you note that your time is 1040. Some of the time lost earlier has been regained. At preplanned speeds, you would have crossed this point at about 1039. You were 2½ minutes behind your flight plan the last time you checked. Now the difference is only about a minute. Things are looking good.

At the 80-mile mark, you cross the very distinct railroad bend and spot the town of Talladega straight ahead. Over Talladega, you make a slight left turn and fly directly to your destination airfield. As you enter the downwind leg for landing, you note that it is 1050. Right on time!

After landing, parking, and going into operations, you make a telephone call to the Anniston FSS to close your flight plan. Now on to the races.

LOST!!!

It seems that all who fly cross-country are destined to lose their way or become "temporarily misplaced" at one time or another. For this reason, you should give some thought to procedures and practices that may be used to lead wandering birdmen out of the wilderness.

The Federal Aviation Administration gives some excellent advice on what to do when you find yourself unsure of where you are:

1. Don't fight the problem; solve it. Stay loose; don't hit the panic button; Panic virtually assures that all the thinking gears will grind to a halt.

2. Analyze and evaluate as to:

a. *Fuel* available and consumption rate. How much longer can you fly with the fuel you have? Be conservative, not hopelessly optimistic.

b. *Weather*. It is good, bad, indifferent, improving, or deteriorating?

c. *Equipment*. Is everything functioning?

d. *Terrain*. Is it open land, flat country, mountains, marshes, semidesert, or sparsely or thickly populated?

e. *Daylight*. How much do you have left? Once you have assessed the situation, you can make vital decisions. One of the first is to decide if help is available, or are you alone?

The following are the steps that you should take if everything, such as fuel, daylight, and weather, is in good shape:

a. Keep going straight. Establishing a course because you have a hunch or because you "got a feeling" is for the birds. Don't wander aimlessly.

b. Use information about your last known position, elapsed time, approximate wind and ground speed (air speed is better than nothing) to establish how far you have traveled since your last check point.

c. Use this distance as a radius and draw a semicircle ahead of the last known position on the chart. For example, on your flight, you flew at 120 mph, and this was about the speed over the ground, too. If you had become lost 10 minutes from a checkpoint, then you would have drawn your semicircle 20 miles from the checkpoint.

d. Loosen up the eyeballs and start some first-class pilotage. Don't overlook the possibility of being lost, yet right on course or very nearly so!! First, look for something big. Don't concern yourself with the minute or trivial at this point unless nothing better is available. Often there will be linear features, such as rivers, mountain ranges, or prominent roads and railroads, which will be easy to spot and identify. If you can't find anything or if you still can't find yourself, use anything that might help, don't pass up a thing. Don't go down low and stay there. As a general rule; it is both safer and easier at higher altitudes.

What should you do if you become lost and you have other problems? Lost and low on fuel; lost with the weather deteriorating; lost with night coming on and no night-flying or instrument experience; lost with engine trouble or some equipment malfunctioning; GET IT ON THE GROUND! Most accidents are the product of mistakes that have multiplied over a period of time. Getting lost is no exception. If terrain or other conditions make it impossible to get down at the moment, don't waste time. Don't search for a field comparable to Kennedy International. Anything usable will do.

Once again, the FAA gives some good advice when you're lost and have other problems:

Never fly until the petrol peters out. There are few things so nerve-shattering as the rustle of the wind when an engine has coughed its last.

Never fly until the sun slowly sinks in the golden west. It may be a beautiful sight, but the goblins will get you if you don't watch out.

Never fly until the biggest and meanest goblin of them all, Ole Bad Weather, falls flat on his face. He will do his best to take you with him.

WORDS AND PHRASES TO REMEMBER

scale
graphic scale
JN chart
ONC
Sectional Aeronautical Chart
pilotage
AIM
NOTAMs
PIREPs
VFR
IFR
linear feature
VFR Pilot Exam-O-Grams

QUESTIONS

1. What is the difference between a chart and a map?
2. The difference between ONCs, JNs, and sectional charts is based on their ________________.
3. What is the definition of chart scale?
4. If two charts are the same size, the one with the ____________ scale will cover a larger area than the one with a ____________ scale.
5. Navigators and pilots of what types of aircraft use JN charts?
6. Match the scales of the following charts:

a. JN	1. 1/1,000,000
b. ONC	2. 1/500,000
c. Sectional	3. 1/2,000,000

7. Where can the date be found when a chart becomes obsolete?

8. There are various methods that show terrain elevation on aeronautical charts. Name two.

9. What is the difference between a prohibited, a restricted, and an alert area?

10. How are prohibited, restricted, and alert areas depicted on the charts?

11. The basic method of light plane navigation is ______________.

12. What are the four parts of the AIM? How often is each part revised and reissued?

13. What is an Oil Burner Route?

14. True or False. A flight plan must be filed on all VFR flights.

15. True or False. Everything on a chart is shown in direct proportion to its real size.

16. On a VFR flight heading west, your flight altitude should be:
    a. 5,000 ft
    b. 5,500 ft
    c. 6,000 ft
    d. 6,500 ft

17. On your hypothetical flight to Talladega Airport, you closed your clearance with a telephone call to the Anniston FSS. How did you know that Anniston was the right FSS? Where did you get the telephone number?

18. What should you do if you find yourself lost and your one and only engine is beginning to run rough?

THINGS TO DO

1. Collect an example of different scale charts and study the different features that are emphasized. Make a report on your observations of all the differences of the charts that would affect pilotage navigation.

2. Take a sectional chart and answer the following questions.
    a. True or False. Airports that are closed are not shown on the chart.
    b. Interpret the following data shown next to the Talladega airport - 526 L 60.
    c. If an airport symbol has a little star on it, what does it have?
    d. How is an abandoned airport symbolized?
    e. On your flight, you flew over Wetumpka Airport. How long is its longest runway?
    f. How is an obstruction below 1,000 feet above ground level depicted?
    g. How is a water aerodrome with no facilities depicted?

Set up two teams and have the instructor ask questions about different features on a chart. The team answering the most correct wins the competition.

3. Obtain an AIM and study all the data that it gives.

4. The FAA VFR Pilot Exam-O-Grams are distributed free to individuals. Write to the FAA and obtain a set for your unit. Also have the unit put on the list for future Exam-O-Grams. Make a report to the class on what Exam-O-Grams are and how they are used.

5. Preplan a pilotage flight on a sectional chart between any two aerodromes. If possible, fly the route that you have planned. If you can't fly it, pretend that you are 26 minutes from your departure point and your engine quits. Where do you go?

SUGGESTIONS FOR FURTHER READING

US Air Force AFM 51–40, *Air Navigation*, Vol. 1, Washington, DC: Department of the Air Force, 1968.

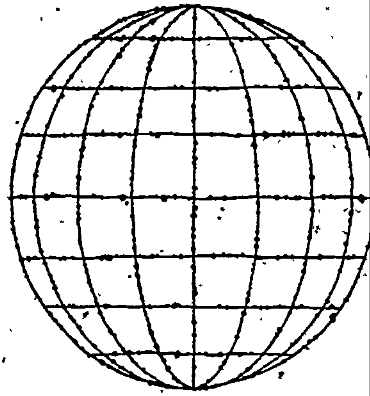
Federal Aviation Administration, "VFR Pilot Exam-O-Grams," Washington, DC: Department of Transportation.

Flight Services Division, *Airman's Information Manual (AIM)*, Washington, DC: Federal Aviation Administration.

LYON, THOBURN C., *Practical Air Navigation*, Denver, Colorado: Jeppeson, 1972.

SANDERSON, *Aviation Fundamentals*, Denver, Colorado: Sanderson, 1972.

Chapter 3



Navigation Elements

THIS CHAPTER explains the navigation method of expressing position, direction, distance, and time. Each of these four basic elements of navigation are explained and various methods of their determination are discussed. After studying this chapter, you should be able to: (1) understand the differences between great circles and small circles; (2) plot positions through the use of latitude and longitude; (3) understand the basic measures of distance and speed; (4) understand the elements of direction; and (5) apply Greenwich Mean Time and zone time concepts.

IN CHAPTER 1, we identified the four basic elements of navigation. position, direction, distance, and time. In chapters 1 and 2, we applied these four elements in our two trips, one driving and one flying. For short flying missions using only pilotage, our method of using these elements might be satisfactory. However, as you increase distance, altitude, and speed and include such factors as weather and heavy traffic, terms like northeast for direction or 10 miles south for position are not adequate. Here, we study in depth the basic elements of navigation. This will enable you to use more sophisticated methods of navigation.

EARTH'S SIZE AND SHAPE

For most navigational purposes, the earth is assumed to be a perfect sphere, although, in reality, it is not. Measured at the equator, the earth is approximately 7,931.5 miles in diameter, and the diameter through the poles is approximately 7,904.6 miles. This difference of 27 miles does not prevent us from assuming the earth to be spherical for navigation purposes. This assumption has proven to be practical since, for centuries, navigators on the water or in the air have reached their destinations based on it.

Great Circles and Small Circles. A **great circle** is defined as a circle on the surface of a sphere whose center and radius are those of the sphere itself. It is the largest circle that can be drawn on the sphere. Figure 13 shows some great circles. The equator is an example of a great circle. Meridians discussed later are great circles.

For the navigator, the single most important aspect of great circles is that the arc, or piece of the circle, is the shortest distance between two points on a sphere. It is just as a straight line is the shortest distance between two points on a plane.

Circles on the surface of the sphere other than great circles are defined as **small circles.** All latitudes, with the exception of the equator, are small circles.

POSITION

The nature of a sphere is such that any point on it is exactly like any other point. In order that points may be located on the

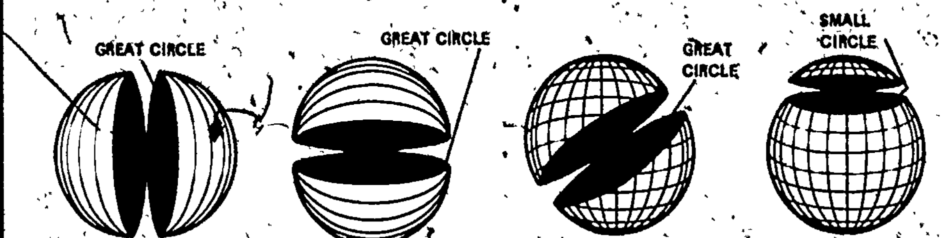


Figure 13. A Great Circle is the Largest Circle on a Sphere.

earth, lines of reference are necessary. In your two navigation problems, you described your destinations, Ft. Walton Beach and Talladega, as so many miles in a certain direction from Maxwell AFB.

This type of position description, however, does not lend itself readily to navigation. It would be difficult to locate a point precisely in the middle of the Pacific Ocean, since there isn't any nearby known geographic feature to use for reference. For that matter, when referring to something as being 10 miles from New York City, from where do you start measuring? This method of describing position is not precise enough for air navigation.

A system using imaginary reference lines has been developed to locate positions on the earth. These lines are known as parallels of latitude and meridians of longitude. The numbers representing a position in terms of latitude and longitude are known as the **coordinates** of that position.

Latitude.—The equator is a great circle midway between the poles, and its plane is perpendicular to a line connecting the poles. Parallel with the equator are lines of **latitude.** Each of these parallel lines is a small circle, and they have a definitive location. The location of the latitude is determined by figuring the angle at the center of the earth between the latitude and the equator. In Figure 14, this angle is 45°. Therefore, this would be the 45° parallel of latitude.

The equator is latitude 0°, and the poles are located at 90° latitude. Since there are two latitudes with the same number (two 45° latitudes, two 30°, etc), the letter designators N and S are used to show which latitude is meant. The North Pole is 90°N and the South Pole 90°S. Thus, the area between the poles and the equator are known as the **Northern** and **Southern Hemispheres.**

Longitude.—We have seen how the north-south measurement of position is figured. With only this information, however, it is still not possible to locate a point. This difficulty is resolved by use of **longitude,** which indicates east-west location.

There is no natural starting point for numbering longitude. Therefore, the solution has been to select an arbitrary starting point. A great many places have been used. When the English speaking people began to make charts, they chose the meridian through their principal observatory in Greenwich, England, as the zero degree line, and this line has now been adopted by most other countries of the world. The **Greenwich Meridian** is sometimes called the first or **prime meridian,** though, actually, it is the zero meridian. Longitude is counted east and west from this meridian through 180 degrees, as shown in Figure 15. Thus, the Greenwich Meridian is the 0 degree longitude on one side of the earth, and, after crossing the poles, it becomes the 180th meridian (180 degrees east or west of the 0-degree meridian). Therefore, we have all longitudes designated either east or west, e.g., 140°E or 90°W, and these designations define the **Eastern** and **Western Hemispheres.**

Finding the Place.—If a globe has the circles of latitude and longitude drawn upon it according to the principles described and if the latitude and longitude of a certain place have been determined, a given point can be located on the globe in its proper position (Fig 16).

Latitude is expressed in degrees up to 90, and longitude is expressed in degrees up to 180. A degree (°) of arc may be sub-

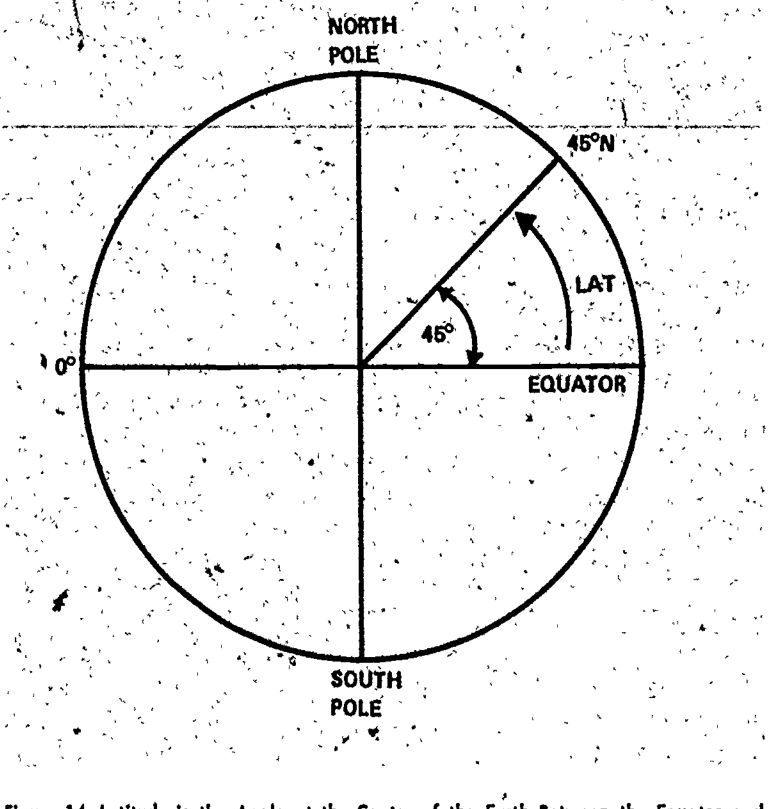


Figure 14. Latitude is the Angle at the Center of the Earth Between the Equator and the Latitude.

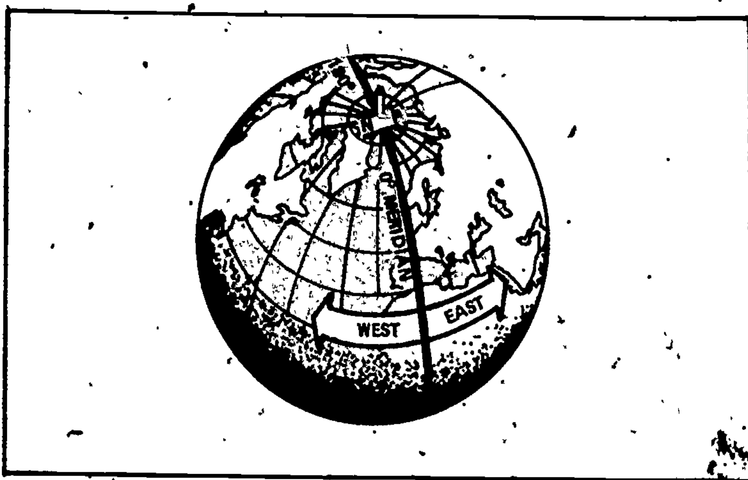


Figure 15. Longitude is Measured East and West of the Greenwich Meridian.

divided into smaller units by dividing each degree into 60 minutes (′) of arc. Each minute may be further subdivided into 60 seconds (″) of arc.

A position on the surface of the earth is expressed in terms of latitude and longitude. Latitude is expressed as being either north or south of the equator, and longitude as either east or west of the prime meridian.

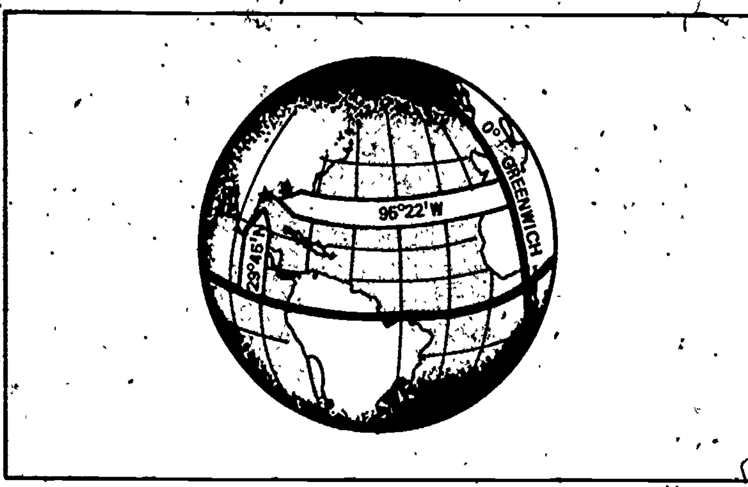


Figure 16. Latitude is Measured from the Equator, Longitude from the Prime Meridian. Together they describe a point on the globe.

On your flight in Chapter 2, you started from Maxwell AFB. Let's suppose that you were looking at a large chart and had no idea where Maxwell is located. All you needed to know was the coordinates of Maxwell, which are 32°23'N 86°22'W, and you could locate it easily. Every point on earth can be located through this system.

Smaller areas can be located by going beyond degrees and minutes and using seconds.

DISTANCE

Distance, as previously defined, is measured by the length of a line joining two points. In navigation, the most common unit for measuring distances is the nautical mile. The **nautical mile** is about 6,076 ft (sometimes rounded to 6,080 ft). It is also equal to one minute of arc on a meridian, which is one minute of latitude.

To convert nautical miles into statute miles, the statute mile figure can be multiplied by the factor 1.15. For example, 10 nautical miles equal 11.5 statute miles. To convert nautical miles to statute miles, you can multiply the nautical miles by .87. For example, 10 statute miles equal 8.7 nautical miles. A measure of distance used in Europe and now being considered for use in the United States is the kilometer, or 1,000 meters. A kilometer equals approximately 0.621 of a statute mile or about .54 of a nautical mile. Appendix B of this book explains a simpler method to make all of these conversions.

Closely related to the concept of distance is speed, which determines the rate of change of position. Speed is usually expressed in miles per hour, this being either statute miles per hour or nautical miles per hour. If the measure of distance is nautical miles, it is customary to speak of speed in terms of **knots**. Thus, a speed of 200 knots and a speed of 200 nautical miles per hour mean the same thing. It is incorrect to say 200 knots per hour.

On your trip in Chapter 2, you flew 120 mph. For navigational purposes, this would convert to 104 knots. From now on, we use nautical miles (nm) for distance and knots (k) for speed.

DIRECTION

Direction is the position of one point in space relative to another without reference to the distance between them. The use of points of the compass specifying direction (north, north-northwest, northwest, west-northwest, west, etc) is not adequate for modern navigation. It has been replaced, for most purposes, by a numerical system.

The numerical system (Fig 17) divides the horizon into 360° starting with north as 000° and continuing clockwise through east (090°), south (180°), west (270°), and back to north.

This circle, called a **compass rose**, represents the horizon divided into 360°. In Figure 17, position B lies at a true direction of 062° from A, and position C lies at a true direction of 295° from A.

Since determination of direction is one of the most important parts of the navigator's work, the various terms involved should be clearly understood.

Course is intended horizontal direction of travel.

Heading is the horizontal direction in which an aircraft is pointed. Heading is the actual orientation of the longitudinal axis of the aircraft at any instant, while course is the direction intended to be made good.

Track is the actual horizontal direction traveled by the aircraft over the earth.

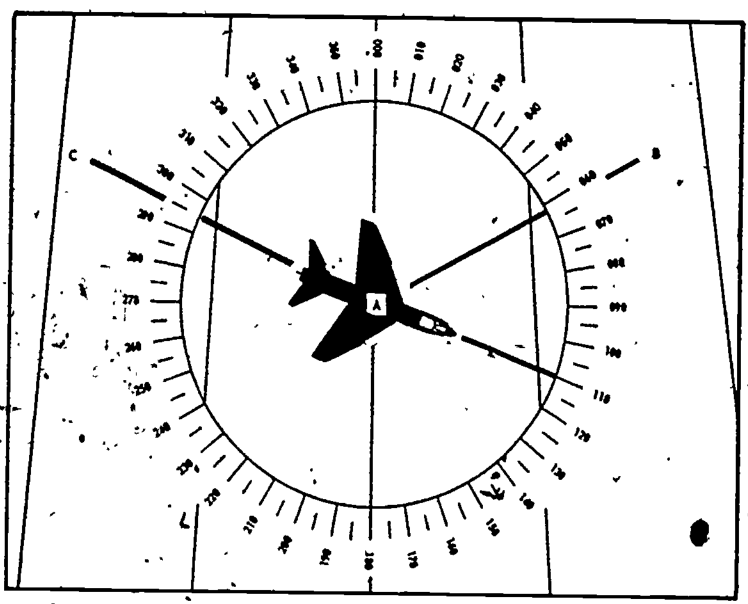


Figure 17. Numerical System Used for Direction. Point B lies at a true direction of 062° from A, and position C is at a true direction of 295° from A.

If we plot a course from New York to London, we see something interesting (Fig 18). The direction of the great circle makes an angle of about 50° with the meridian of New York, about 90° with the meridian of Iceland, and a still greater angle with the meridian of London. In other words, the direction of the great circle is constantly changing as progress is made along the route, and it is different at every point along the great circle. Flying such a route requires constant change of direction and would be difficult to fly under ordinary conditions. Still, it is the most desirable route, since it is the shortest distance between any two points.

A line that makes the same angle with each meridian is called a **rhumb line.** An aircraft holding a constant true heading would be flying a rhumb line. Flying this sort of path results in a greater distance traveled, but it is easier to steer. Between two points on the earth, the great circle is shorter than the rhumb line, but the difference is negligible for short distances (except in high latitudes).

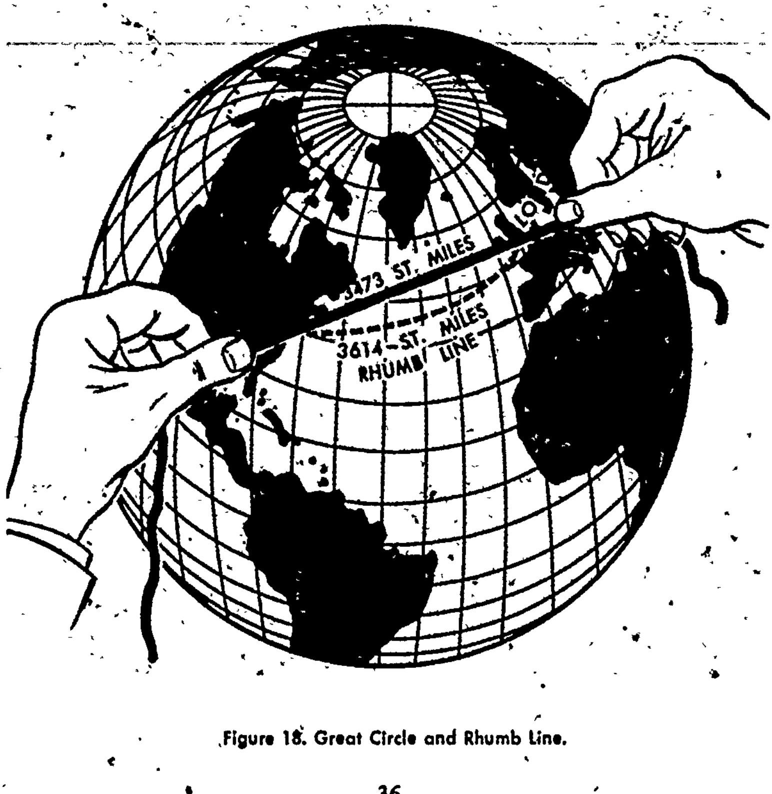


Figure 18. Great Circle and Rhumb Line.

TIME

The earth makes a complete rotation of 360° during a 24 hour day. The Equator could, therefore, be divided into 24 hours as well as 360°. One hour represents 15° of longitude. Longitude, as we have seen, is expressed in degrees, minutes, and seconds. It is also possible to express longitude in hours, minutes, and seconds of time. For example, a point at 60° longitude may be expressed as four hours west of Greenwich.

Zone time.—Before the establishment of zone time in 1883, every city and town had its own time. As you may well imagine, this situation caused much confusion. Once time zones were established, there was less confusion.

Each time zone is 15° of longitude (one hour of angular measure) in width, and the first zone centers on the prime meridian. However, irregularities have crept into the system because some towns have decided to keep the time of some large city farther west or east. Further confusion entered the picture when "Daylight Saving Time" was introduced. This set the clocks in the affected area one hour ahead.

In Figure 19, you can see that the United States has four standard time zones. The time in any given zone is one hour earlier than in an adjacent eastern zone and one hour later than in an adjacent western zone.

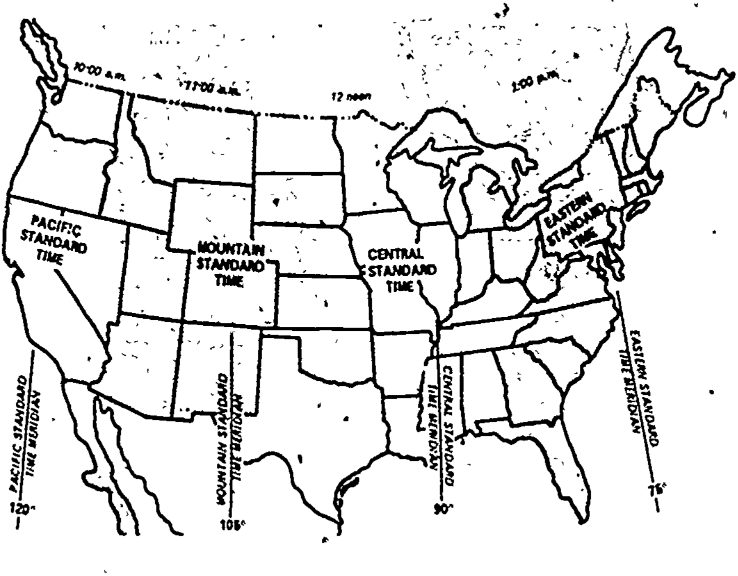


Figure 19. Standard Time Zones in the United States.

Pilots sometimes become confused in reporting their **estimated time of arrival (ETA)** because they cannot remember whether they must add or subtract an hour. Most pilots use one of two methods to give the correct time. First, some pilots give their ETA according to the time that their watch indicates. If their watch is set to central standard time (CST), then they specify CST when giving their ETA to the tower. For example, a pilot's ETA is radioed in as 1630 central standard time. The tower personnel then know at what time the pilot expects to arrive. They can determine the correction necessary for their specific zone.

Greenwich Mean Time.—The use of Greenwich Mean Time avoids the necessity of considering time zones. **Greenwich Mean Time (GMT)** is the time of day at any given moment at Greenwitch, England. If GMT is employed and a pilot requests clarification, he will be given the local standard time. For example, you request clarification of the time and receive the following: 1745 Greenwich, 1245 Eastern. Greenwich time is often noted on communications and teletype reports as **Z.** It is therefore often called "Zulu" time, in accordance with the international phonetic alphabet.

The following table should be hlepful in converting from standard time to Greenwich Mean Time.

To Convert From:	To Greenwich Mean Time
Eastern Standard	Add 5 hours
Central Standard	Add 6 hours
Mountain Standard	Add 7 hours
Pacific Standard	Add 8 hours

Daylight Saving Time is usually never used for aviation purposes. To convert from GMT during Daylight Saving Time, add one hour to the tabulated values shown above for GMT.

WORDS AND PHRASES TO REMEMBER

great circle
small circle
coordinates
latitude
Northern Hemisphere
Southern Hemisphere
longitude
Greenwich Meridian
prime meridian
Eastern Hemisphere
Western Hemisphere
nautical mile (nm)
knots (k)
compass rose
course
heading
track
rhumb line
zone time
ETA
GMT
Z

QUESTIONS

NOTE: In the true/false questions, if false, tell why.

1. True or False. The earth is a perfect sphere.
2. If a circle is drawn around the surface of the earth and its center and radius are the same as the earth's, it is a ____________ circle. Name two examples of this kind of circle.
3. True or False. The shortest distance between two points on earth is a straight line.
4. True or False. All latitudes are small circles.
5. Match the following:

a. 0° latitude	a. prime meridian
b. 90°N	b. South Pole
c. 90°S	c. North Pole
d. 0°E/W	d. Equator

6. What are the coordinates of your town?
7. Convert the following:

Nautical Miles	Statute Miles	Kilometers
100	________	________
________	100	________
________	________	100

8. Convert the following to degrees on a compass rose:

North________	Southeast________	West________
Northeast________	South________	Northwest________
East________	Southwest________	

9. If you intend to fly due east or 090, this is your ______________. To fly 090, the aircraft actually points toward 095 due to various corrections. This is your ______________. To get to your destination, the path that you flew over the ground is the ______________.
10. True or False. An aircraft holding a constant true heading would fly a great circle.
11. A point with coordinates 36°N 75°W is ______________ hours west of the prime meridian.
12. Convert the following:

Local Standard		Z
______________	Central	1200
______________	Eastern	1600
______________	Pacific	0001 1 January 1975
2100 Mountain, 31 Dec. 1975		________ ________ Date

THINGS TO DO

1. Obtain a globe and plot the general coordinates of the following:

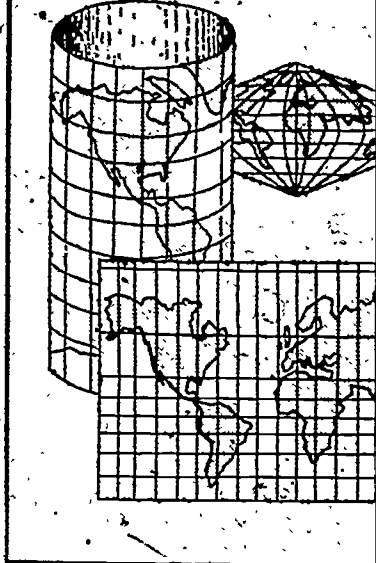
New York City	Bangkok, Thailand
London, England	Peking, China
Rome, Italy	Honolulu, Hawaii
Moscow, Russia	Los Angeles, California

   Plot areas on a map of the world that are prominent in the news.

2. Working with a globe, place a string between two points and demonstrate to the class the difference between rhumb line and great circle route flying.

3. As you drive down the road, practice mentally converting posted speeds and mileage into kilometers and nautical miles.

4. Using Appendix A to this text as a guide, measure the direction that you would have to fly to get from various points such as:
   a. Your town to Miami, Florida
   b. Washington, DC, to Los Angeles
   c. From the Pacific side of the Panama Canal to the Atlantic side.
   d. Los Angeles, California, to Reno, Nevada



Chapter 4

"If It Were Only Flat"

THIS CHAPTER introduces you to the differences in chart projections, their use, and their limitations. When you have studied this chapter, you should be able to: (1) explain how the different projections are developed, (2) understand the differences between azimuthal, cylindrical, and conic projections, (3) know the difference between gnomonic and stereographic projections, (4) understand the different uses of the Lambert Conformal, Mercator, and Gnomonic charts.

When the ancient mariners first ventured from their shores into the vast unknown sea, their charts were amazingly simple. These brave men made the assumption that the world is flat, and, when you disappeared over the horizon, you disappeared. Since they rarely ventured out of sight of the coast, they had no need for a coordinate system. There was no need to worry about whether the shape of that island was exact or not. There was no need for precise navigation.

Before you complete this chapter, you may long for "the good ole days." The idea of a spherical earth confronted early cartographers or mapmakers with the problem of portraying the earth's spherical surface on a flat chart.

Hipparchus (160-125 BC), the inventor of trigonometry, originated the basic azimuthal projections—the orthographic and the stereographic—which are in use to this day. From the time of Hipparchus to the present jet age, there have been advancements in devising new map projections. At last count, there were over 250 different projections available. Each of these has special characteristics to serve a particular purpose.

THE PROBLEM

In the last chapter, we learned that the earth's surface is divided into a system of imaginary lines of parallels and meridians called latitude and longitude. This system is called a **graticule.**

The problem in trying to represent the earth's graticule and surface features on the flat surface of a chart is that the earth, a globe, or any spherical surface is undevelopable. An **undevelopable surface** is one that cannot be flattened. No matter how many times an undevelopable surface is cut or split, it cannot be completely flattened. Just as an orange cannot be flattened without tearing and distorting the peel, any attempt to represent even a small portion of the earth's surface on a flat plane results in distortion (Fig 20).

A **developable surface** is any three-dimensional geometric figure, such as a hollow cone or cylinder, which may be cut and laid flat without distorting any features on its surface (Fig 21).

A **projection** is the method of transferring the earth's graticule and surface features onto a plane or onto the developable surface of a cone or cylinder. In practice, this is done mathematically, but it can be explained more satisfactorily through geometric projection. A light within a hollow plastic model of the earth which projects the graticule and surface features onto a plane or developable surface is an example of a geometric projection (Fig 22).

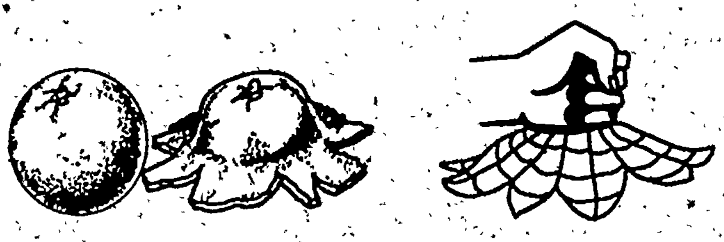


Figure 20. Undevelopable Surfaces.

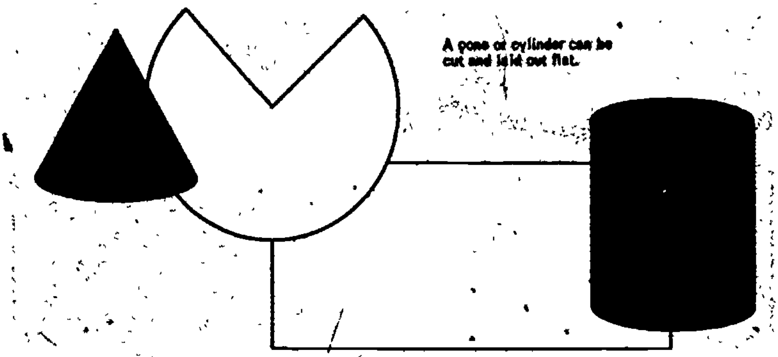


Figure 21. Developable Surfaces.

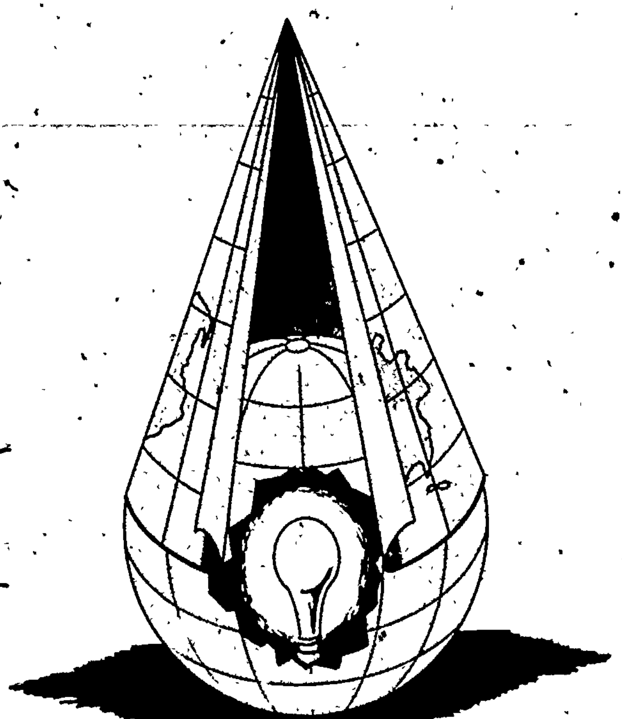


Figure 22. A Projection.

Distortion of direction, distortion of the relative size of areas, and distortion of the shape of areas on the earth is the direct result of projecting the earth's graticule onto a flat or developable surface. Even a small portion of the surface of a sphere, globe, or the earth is undevelopable, since it will not lie completely flat. Different types of projections produce different types of distortion on charts.

Distortion of size may be seen on many maps. For example, Greenland is sometimes shown as covering more area than India. Since India is actually larger than Greenland, the relative size of the chart areas is distorted through these projections. When a chart misrepresents the State of Texas as a long thin area, the shape of the state is distorted even if its relative size is truly represented. Parallels and meridians should intersect on charts at right angles or 90°, as they do on earth. Distortion of direction on chart projections occurs when latitude and longitude do not intersect correctly (Fig 23).

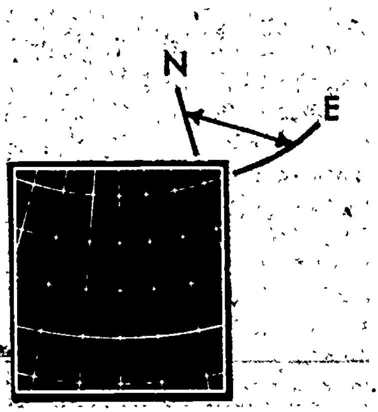


Figure 23. Direction Distortion.

PROJECTION CLASSIFICATION

Projections are classified according to three considerations: type of surface, point of tangency, and point of projection. The name of a projection depends, in part, on geometric figures onto which the surface of a model of the earth is projected. These figures include a plane, a cone, and a cylinder. Remember the name of the chart used on your flight to Talladega? It was a Lambert Conformal Conic Projection.

The second consideration for projection classification is the point of tangency. A plane can touch or be tangent to the earth at only one point. The location of the point of tangency is also reflected in the name of the projection. For example, a polar projection is tangent at one of the poles (Fig. 24).

A cylinder is tangent to a model of the earth along a complete great circle. When this circle is the equator, it is called a parallel of tangency or a **standard parallel.** The cone is also tangent at a parallel (Fig 25).

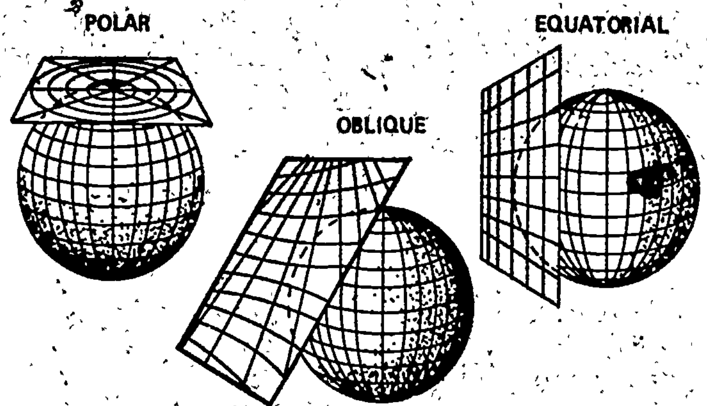


Figure 24. Plane Point of Tangency.

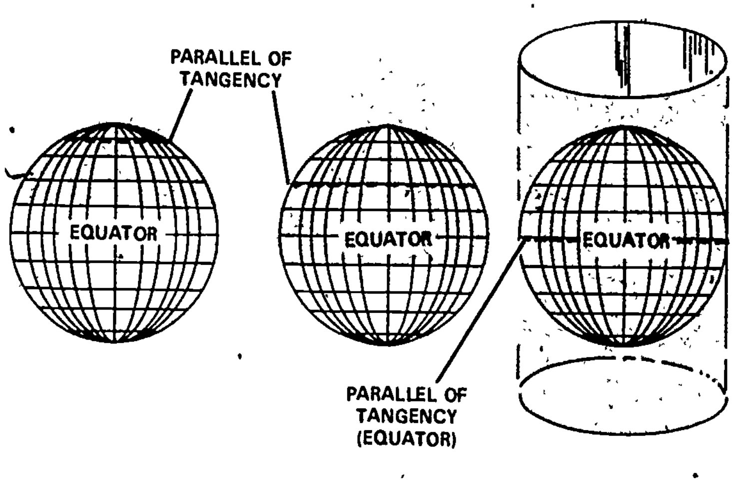


Figure 25. Conic and Cylindrical Projections Showing the Parallel of Tangency.

The third projection classification is concerned with the **point of projection.** Earlier in Figure 22, we showed how some projections are made by assuming a light to be in the center of the earth and by projecting the surface of the earth onto a flat surface. This type of projection is called a **gnomonic.** The point of projection is the origin of the rays that project a graticule onto a geometric figure. Most conic and cylindrical projections have their point of projection at the center of the earth and are gnomonic projections. The other origin point of the projection rays is a point on the surface of the earth opposite the point of tangency. This type of projection is called a **stereographic** projection (Fig 26).

CHART PROJECTION CHARACTERISTICS

Many characteristics are desirable in a chart. The ideal chart projection would portray the features of the earth in their true relationship to each other: directions would be true; distance would be true, and distance would be represented at a constant scale over the entire chart.

Such a relationship can only be represented on a globe. On a flat chart, it is impossible to preserve constant scale and true direction for all directions at all points. Also, relative size and shape

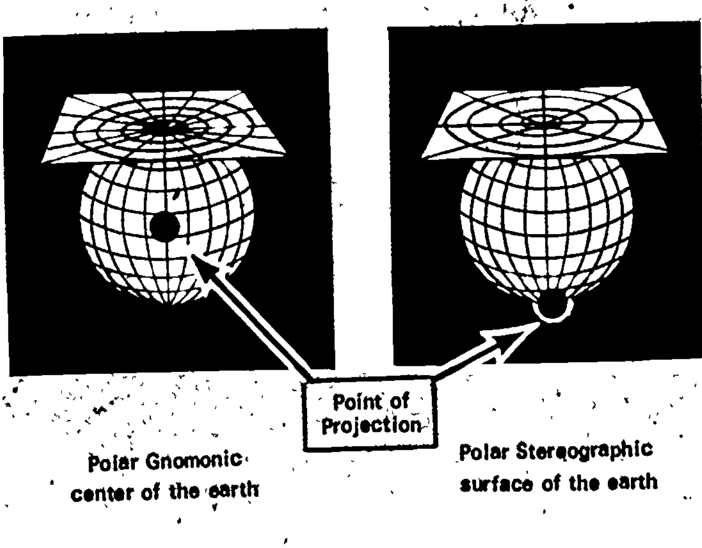


Figure 26. Two polar Projections with Different Points of Projection.

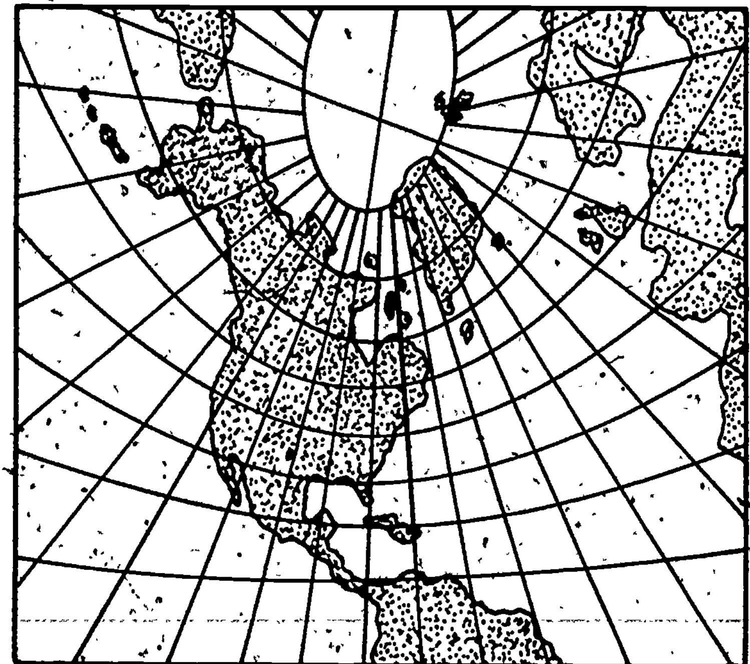


Figure 57. A Gnomonic Chart showing the inherent distortion.

of the geographic features cannot be accurately portrayed throughout the chart.

Gnomonic charts are planning charts. The graticule in a gnomonic projection (Fig 27) is so greatly distorted that it is not used for navigation except in planning the Great Circle course. It is used only for great circle planning because the Great Circle course appears as a straight line on the gnomonic projection (Fig 28).

The polar stereographic projection with its point of projection located at the opposite pole causes increasing distortion as you move to the outer edges of the projection (Fig 29). **Polar stereographic charts** may be used for navigation only within 30° of the pole that is the point of tangency.

Of the many projection characteristics that are desirable for charts, the most important for air navigation charts is conformality. Even though conformal charts have some undesirable characteristics, the disadvantages of this type of projection are far outweighed by the advantages.

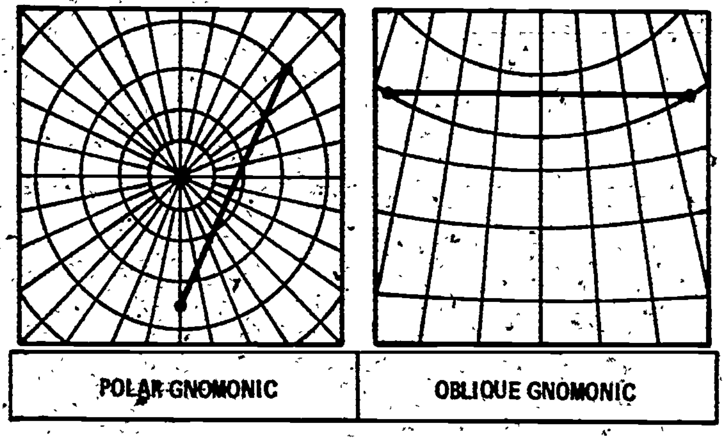


Figure 28. Great Circle Routes appear as straight lines on Gnomonic Projections.

A **conformal chart** shows all angles as they actually appear on earth. The graticule of a conformal chart shows parallels and meridians intersecting at 90° angles just as they do on earth. As a result of angles being accurately reproduced, the directions and true shapes of areas are shown on any conformal chart. This occurs even though the relative size of areas may be distorted.

If we look down on a globe, we see that the meridians converge at the poles. Meridians on the earth are not parallel lines. Therefore, as the latitude increases on the earth's surface, the distance between parallels remains the same, but the distance between meridians decreases.

The equatorial **Mercator** is a projection onto a cylinder that is tangent to the parallel of tangency along the equator. Its point of projection is found at the earth's center.

The Mercator, as it is normally identified, is a conformal chart, with parallels appearing as straight parallel lines. Since it is conformal, the meridians must cross the parallels at 90° angles. To do this, the meridians are projected as straight parallel lines that do not converge toward the poles as they do on earth. The spaces between the meridians have been stretched east and west to change them from converging to parallel lines (Fig 30).

If the spaces between the meridians are stretched east and west, then the spaces between the parallels must be stretched north and south to keep the proportion or conformality (Fig 31).

In Figure 32, note that the distance between parallels in both diagrams are increasingly farther apart as the distance from the Equator increases.

In projecting the earth's graticule and surface features onto any chart, some distortion always occurs. The parallel (or point) of tangency is the only area of a chart without distortion. Distortion of features becomes greater as you move away from the parallel of tangency. For this reason, the Mercator is used only for navigation within 60° above and below the Equator.

Scale is correct only at the Equator. Since the distance between parallels expands as the altitude increases, the scale that we use for measuring distance in nautical miles also expands. When we measure distance on the Mercator, we must always use the scale

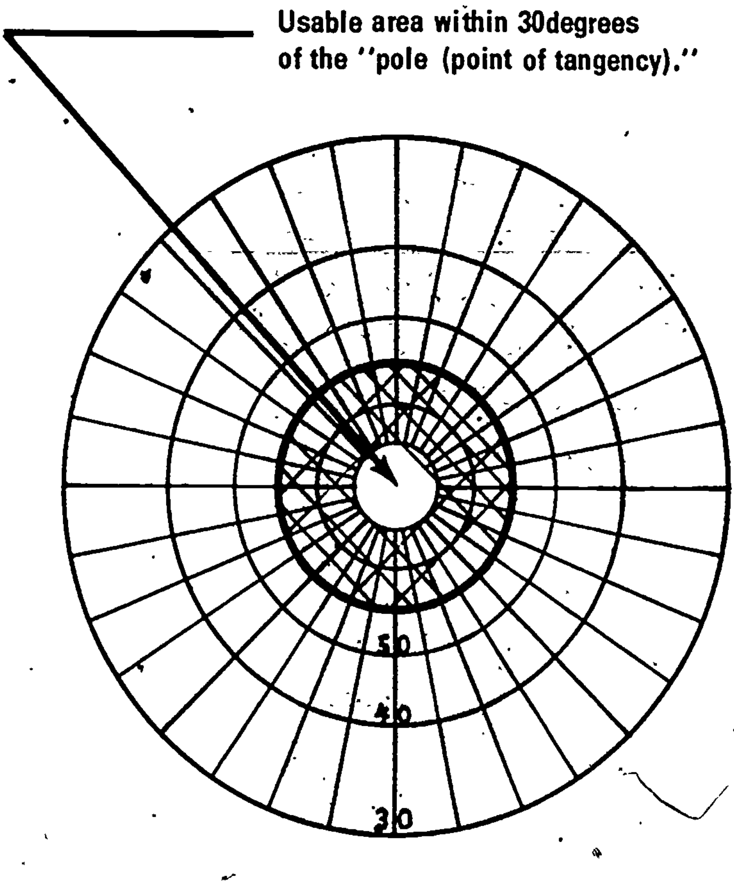


Figure 29. Polar Stereographic Projection.

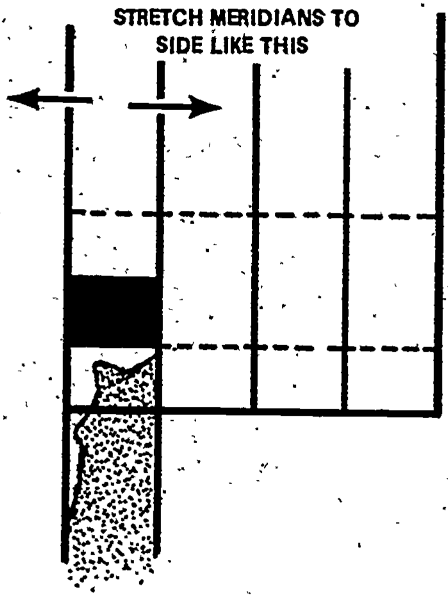


Figure 30: Meridians are stretched East and West on a Mercator Projection.

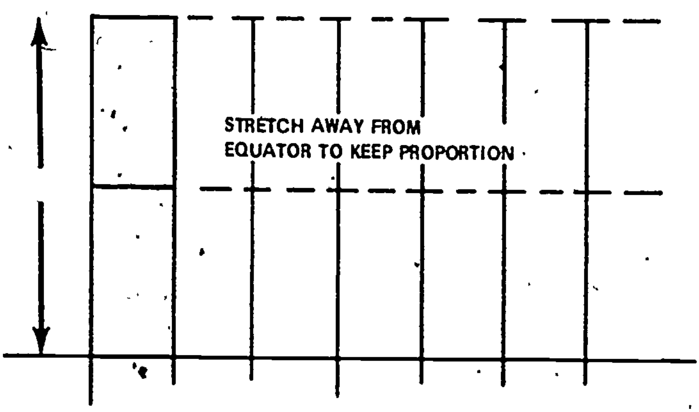
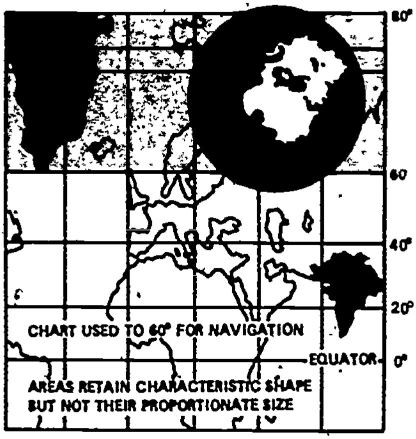


Figure 31 Since Meridians are stretched on a Mercator Projection, Parallels must also be stretched.



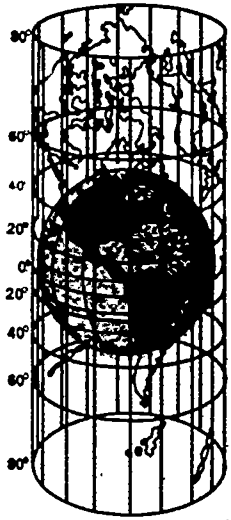


Figure 32. The Mercator Projection showing how the distance between parallels expand the further away you move from the point of tangency.

at that specific latitude. To measure distances between two positions at different latitudes, we use the scale at the mid-latitude along the course.

The Mercator projection distorts the true appearance of a rhumb line and a great circle. On the Mercator chart, a rhumb line appears as a straight line, but a great circle appears as a curved line (Fig 33). This is directly opposite from what is true on a globe or the earth. The only great circle courses that appear straight on a Mercator chart are those drawn along the Equator or a meridian.

Thus far, we have looked at charts that are based on azimuthal projections (gnomonic and stereographic) and cylindrical projections (Mercator). Another type of projection is the conic projection.

Most conic projections have their point of projection at the earth's center. A simple conic projection is tangent along some parallel of latitude between the Equator and a pole. Where the equatorial Mercator is tangent to a parallel that is a great circle, the conic projection is tangent to a parallel that is a small circle. This line where the cone touches the earth is called the **parallel of tangency** (Fig 34). Another name for the parallel of tangency is standard parallel.

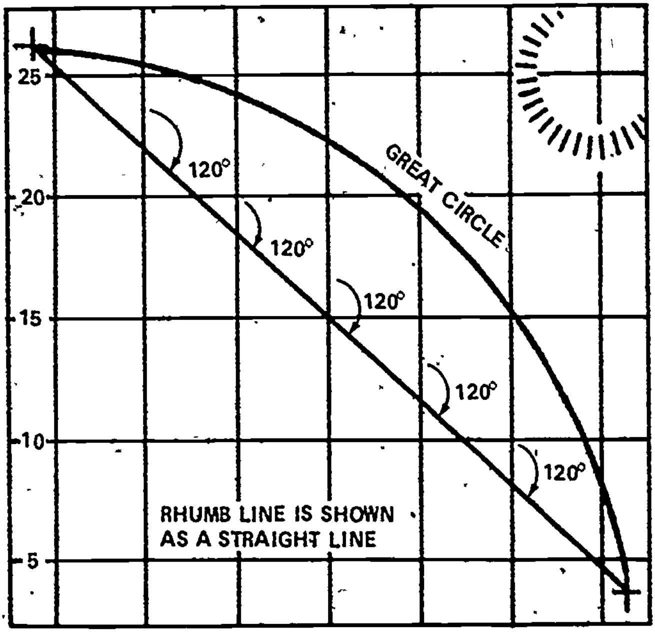


Figure 33. Mercator Projections show Rhumb Lines as straight lines and Great Circles as curved lines.

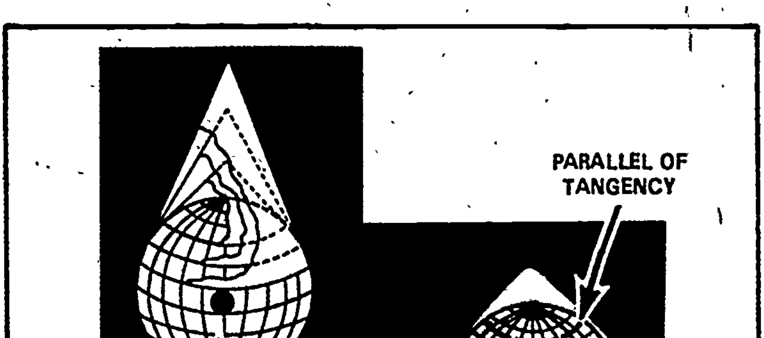


Figure 34. Conic Projection showing the Point of Projection and Parallel of Tangency.

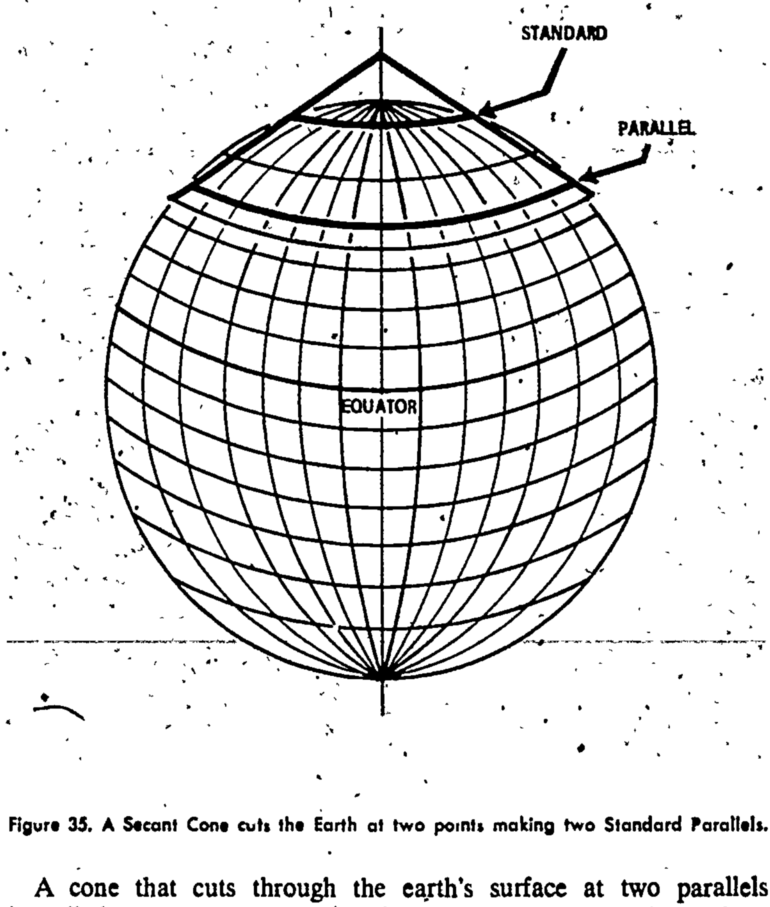


Figure 35. A Secant Cone cuts the Earth at two points making two Standard Parallels.

A cone that cuts through the earth's surface at two parallels is called a **secant cone.** Therefore, we have two points where the cone contacts the earth giving two standard parallels (Fig 35).

The chart used most in navigation is projected onto a secant cone. It is called the **Lambert Conformal Chart.** We used this type of projection on your flight to Talladega, and we saw that the Atlanta sectional had the standard parallels 33°20′ and 38°40′.

Since angles on the earth's surface are correctly shown on any conformal chart, parallels and meridians on the Lambert Conformal's graticule intersect at 90°. To do this, the Lambert Conformal's graticule shows meridians converging and parallels as arcs of parallel circles (Fig 36).

Distortion on the Lambert Conformal constantly increases beyond its two standard parallels. Ordinarily, there is very little distortion between the standard parallels. However, the larger the distance between these standard parallels, the more the distortion. In any case, the Lambert Conformal should be used for navigation between its standard parallels. A gnomonic should not be used for actual navigation.

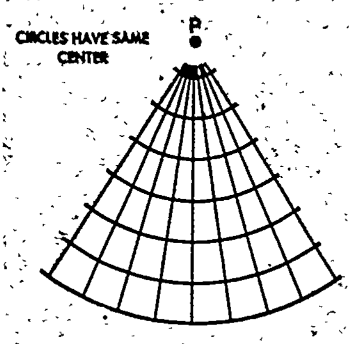


Figure 36. Lambert Conformal Graticule. All angles are 90°

A great circle course appears as a straight line only on a gnomonic projection. The Great Circle route is a curved line on a Mercator chart and approximates a straight line on a Lambert Conformal. A rhumb line is a straight line on a Mercator and a curved line on a Lambert Conformal projection.

When measuring the direction of a line, we use a meridian as a reference line (See Appendix A). Direction is measured clockwise from the meridian. Since all meridians are parallel straight lines on a Mercator, we can measure the direction of a rhumb line using any meridian as a reference. To measure this line on a Lambert Conformal, we must use the mid-meridian because the line will have different directions when measured at different meridians. This is necessary because meridians converge toward the poles (Fig 37).

The Lambert Conformal has a nearly constant scale. When measuring distance on the Lambert, we can use the scale at any latitude between the two standard parallels. On a Mercator, the distance must be measured using the scale of the mid-latitude because the scale expands.

We have discussed only a few of the many chart projections. At the present time, the Lambert Conformal is used more than other charts.

WORDS AND PHRASES TO REMEMBER

graticule
undevelopable surface
developable surface
projection
point of tangency
standard parallel
point of projection
gnomonic projection
stereographic projection
Gnomonic charts
polar stereographic chart
conformal chart
Mercator chart
parallel of tangency
secant cone
Lambert Conformal Chart

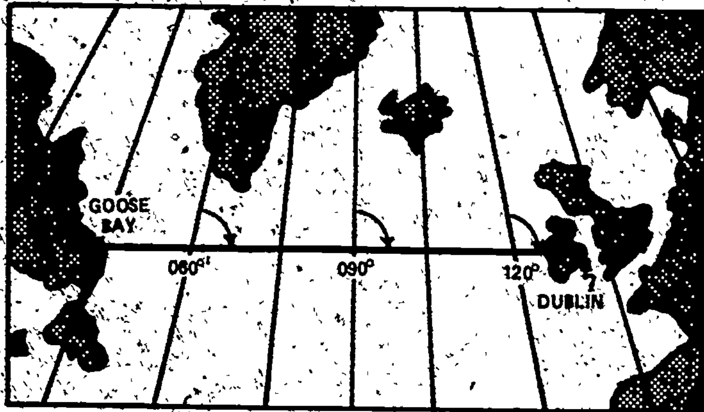


Figure 37 A straight line course on a Lambert Conformal starts out at approximately 060 degrees, ends up aproximately 120 degrees. The average direction is 090 degrees.

QUESTIONS

1. Match the following on a piece of paper:

a. graticule	1. orange peel
b. undevelopable surface	2. cylinder
c. developable surface	3. transfer of graticule
d. projection	4. parallels and meridians

2. Explain what the basic problem is in displaying the earth on charts.
3. What are the three types of distortion found on charts?
4. What kind of distortion is caused when the meridians and parallels do not cross at 90° angles?
5. What are the three considerations for classification of projections?
6. What are the three basic geometric figures used in chart projection?
7. Name three points of tangency for a plane.

______________ ______________________

9. What is the difference between a gnomonic and a stereographic projection?
10. What would be the characteristics of an ideal chart? Are they possible?
11. Are gnomonic charts used for navigation? Why?
12. A great circle is a (straight/curved) line on a gnomonic projection.

13. Polar stereographic charts may be used for navigation only within ________ degrees of the point of tangency.
    a. 10
    b. 20
    c. 30
    d. 60

14. What is the most important characteristic for air navigation charts?

15. Name the advantages of a conformal chart.

16. Name two types of conformal charts.

17. Where is the area on a chart with the least distortion?

18. The Mercator chart is used for navigation between two points that are:
    a. 60°E to 60°W
    b. 60°N to 60°S
    c. 90°N to 90°S
    d. 0°E/W to 180°E/W

19. Distortion (increases/decreases) as you move away from the point of tangency.

20. How do we measure distance on a Mercator?

21. On a Mercator, the rhumb line is (curved/straight) and the great circle is (curved/straight). Are there exceptions?

22. Name an example of an azimuthal, cylindrical, and conic projection.

23. The point of projection for conic projections is usually where?

24. True or False. The point of tangency for a conic projection is a great circle.

25. What is a secant cone?

26. Which chart is most used for air navigation?

27. Lambert Conformal Charts have how many points of tangency? What are they called? Why are they important?

28. True or False. A great circle is a straight line on a Lambert Conformal Chart.

29. We normally use a (meridian/parallel) to measure a direction.

30. How do we measure direction on a Mercator? A Lambert Conformal?

31. How do we measure distance on a Lambert Conformal?

THINGS TO DO

1. Use two different types of projections, preferably a Lambert Conformal and a Mercator, and measure the true course and distance between two points at least 1,000 miles apart. Describe the differences of distance, difficulties in measuring course and distance, and the distance between the courses at the point of greatest separation.

2. Collect examples of as many different kinds of chart projections as you can find. Point out their uses and disadvantages. Give a short explanation of how they were developed.

3. Buckminister Fuller developed a projection that is claimed to be without distortion. It is called a *Dymaxion*. Conduct research on this projection and report on it. Include in your report the reason why this apparently amazing work has not received much attention.

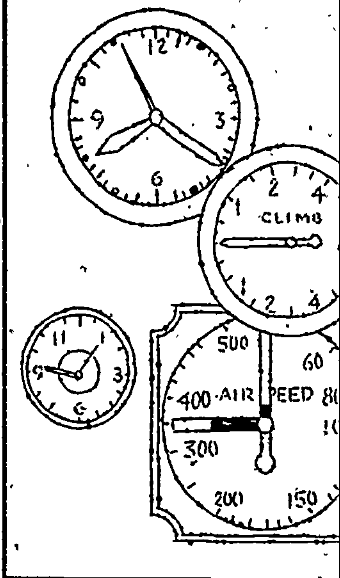
SUGGESTIONS FOR FURTHER READINGS

US Air Force AFM 51-40, *Air Navigation*, Vol 1, Washington, DC: Department of the Air Force, 1968.

KERSHNER, WILLIAM K. *The Student Pilot's Flight Manual*, Ames, Iowa. Iowa State University Press, 1972.

LYON, THOBURN C. *Practical Air Navigation*, Denver, Colorado. Jeppeson, 1972.

SANDERSON, *Aviation Fundamentals*, Denver, Colorado. Sanderson, 1972.



Chapter 5

Navigation Instruments

IN THIS CHAPTER, the basic instruments necessary for elementary navigation are discussed. Also discussed are various altitudes and headings. After studying this chapter, you should be able to: (1) understand the uses of the basic navigation instruments, (2) explain how five types of altitude differ, (3) understand headings used in Air Navigation, and (4) explain the difference between a magnetic compass and a gyrocompass.

IN USING the four elements of navigation—position, time, direction, and distance—for your flight to Talladega in Chapter 2, we used certain instruments that are basic to all navigation. One of the primary instruments is the clock. To insure that you made good your planned airspeed, you used the airspeed indicator. You climbed to 5,500 feet and changed altitudes several times. To do this, you used the altimeter. On your flight, you talked of direction only in very broad terms. Anyone who has flown knows that, in reality, you should have figured compass headings for each part of your flight. To follow these headings, you use the aircraft compass. This illustrates the use of the four basic navigation instruments: (1) a clock, (2) airspeed indicator, (3) altimeter, and (4) compass (Fig 38).

Instruments mechanically measure physical quantities or properties with varying degrees of accuracy. Most of the pilot/navigator's work consists of figuring corrections to the indications of various instruments and applying the results to find the four elements of the navigation problem.

The instruments that we discuss in this chapter are the absolute minimum necessary for flying today. As we shall see later, there are many more sophisticated navigation instruments. Also, the FAA has now recommended that all private pilots be taught to perform each flight maneuver with both visual references outside of the aircraft and by reference to instruments only. Although this instruction is not compulsory, it is required that private pilots be able to control aircraft attitude by instruments alone. This requirement adds the **attitude** or **turn-and-bank indicator** to the list of basic instruments for navigation. Flying by instruments in this manner is called flying "needle, ball, and airspeed." Attitude indicators are covered in Theory of Aircraft Flight.

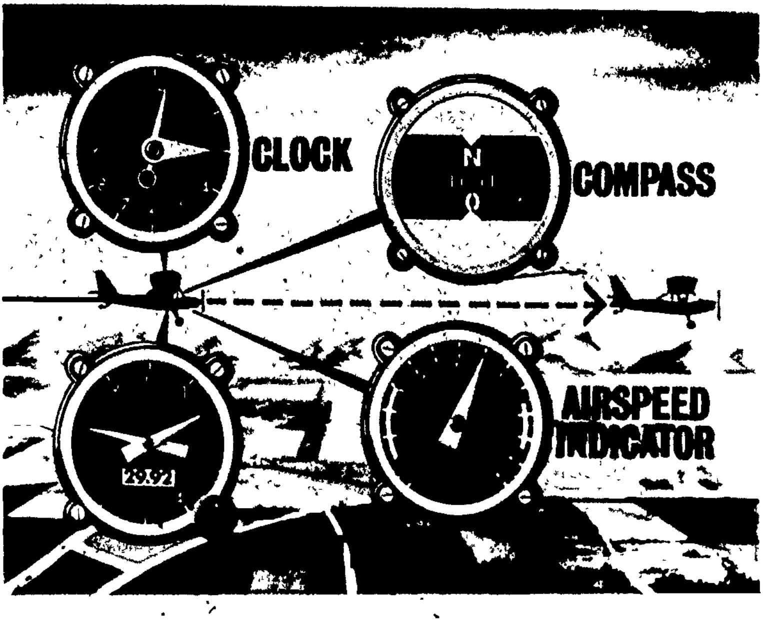


Figure 38. Basic Navigation Instruments.

THE CLOCK

The clock is the simplest instrument and one of the most important instruments for navigation. The estimated time of arrival (ETA) is frequently updated. On your flight in Chapter 2, we referred to your flying time and compared it with the preplanned times throughout the flight. One of the first indications of trouble occurs when you start to miss your planned times over checkpoints. This usually means that wind shifts have occurred.

Fuel consumption is computed in time. Any changes in time affect the amount of fuel that you will have at your destination. If you start out with three hours of fuel on board and run into situations that start extending your flying time (such as avoiding weather or getting lost), you must figure your fuel very closely.

Any good timepiece is suitable for indicating elapsed time, and it is not necessary to have an elaborate clock or chronometer for simple navigation. One technique used by some pilots to minimize errors in calculating elapsed flight time is to set the aircraft clock at 12 o'clock upon leaving the airport. With this arrangement, the pilot can read elapsed flight time at a glance. He can easily obtain the correct time of day from his own wristwatch.

AIRSPEED INDICATOR

An airspeed indicator measures an aircraft's speed in flight rather than its groundspeed. **Airspeed** is the speed of an aircraft with respect to the air through which it moves. **Groundspeed** is the speed of an aircraft measured by the distance that an aircraft travels over the ground in a given time. Because these two speeds often differ, it is important that pilots do not confuse them. The airspeed indicator consists of a **pitot tube,** airtight diaphragm, a linkage assembly, and a dial with a pointer (Fig 39). It measures the difference between the increased air pressure caused by the motion of the craft and the pressure of air contained in the case of the airspeed indicator.

As the speed of an aircraft increases, the impact air increases over the pitot tube and the static or undisturbed air remains the same within the instrument case. This difference in pressure causes the diaphragm to expand, forcing the dial that is attached by mechanical linkage to move and indicate the airspeed upon the face of the indicator. This indication may appear in miles per hour or knots, or both, depending upon the type of instrument. Most indicators now read airspeed in knots.

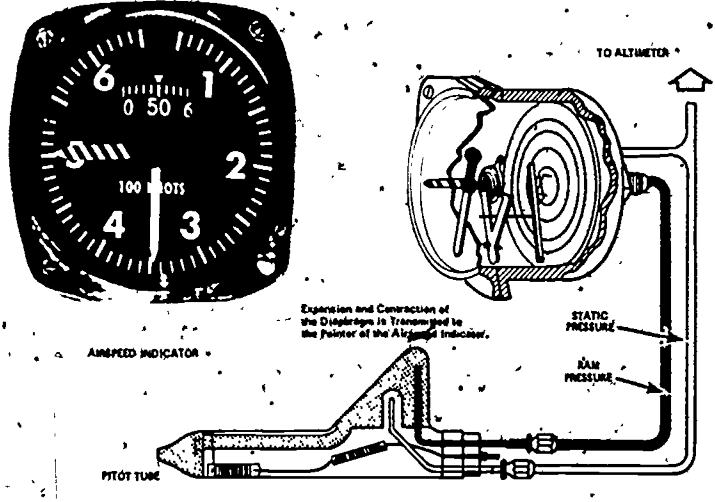


Figure 39. Airspeed Indicator Component Parts.

The accuracy of the instrument is affected by instrument error, installation error, and the density of the air. Corrections can be made by having the indicator checked periodically to insure its accuracy.

We now discuss three kinds of airspeed: (1) indicated airspeed, (2) calibrated airspeed, and (3) true airspeed.

Indicated airspeed (IAS) is the instrument reading taken directly from the airspeed indicator. It has not been corrected for any variation in atmospheric pressure, installation error, or instrument error.

Calibrated airspeed (CAS) is airspeed that has been corrected for installation error and possible instrument error. Since it is impossible to eliminate all instrument error, there is always a need to compensate for this error. At certain speeds and altitudes, the installation and instrument errors may amount to several miles per hour. The greatest potential for error lies in the low airspeed range. Indicated airspeed and calibrated airspeed are normally about the same in the high altitude and cruising airspeed ranges. To determine the calibrated airspeed, pilots refer to the airspeed calibration charts, which indicate errors caused by the instruments or installation. These charts are usually placed near the airspeed indicator or are included within the Airplane Flight Manual or owner's manual.

Since leaks may develop in the airspeed indicator assembly, it is important to take good care of the entire system. Dirt, dust, ice, and snow may damage the system and render the indicator inoperable. Even regular aircraft vibrations may influence the sensitive mechanism, resulting in erroneous readings. Therefore, it is imperative that the indicator be checked periodically to assure operating effectiveness.

It is often difficult to determine the actual or **true airspeed (TAS)** of an aircraft. An airspeed indicator registers airspeed based on standard sea level conditions. Standard sea level conditions exist when atmospheric pressure is 29.92 and the temperature is 15°C (55°F). As an aircraft flies to a higher altitude, the air density decreases, creating errors in indicators of true airspeed. In other words, for a given indicated airspeed, true airspeed increases with increasing altitude.

Pilots use several methods to find their true airspeed. The first method, that of using a computer, is the most accurate. This method corrects the calibrated airspeed for temperature and air pressure by using the airspeed correction scale on the computer. See Appendix B for an example of this method.

The second method of finding the true airspeed is not as accurate as the first, but it is acceptable when there is no computer aboard. The simple rule is to add two percent of the indicated airspeed to the indicated airspeed for each 1,000 feet of altitude. For example, the indicated airspeed is 120 mph at an altitude of 4,000 feet. The true airspeed would then be:

$$2\% \times 120 = 2.40$$
$$2.40 \times 4 = 9.60$$
$$120 + 9.60 = 129.6 \text{ mph (TAS)}$$

A third method is similar to the one above. Simply add two mph to the indicated airspeed for each 1,000 feet of altitude. If we use the figures from the last example, we see that this method gives us an answer of 128 mph (TAS). Neither of these two answers is precisely correct, but these computations give quick approximations, and they are used frequently by pilots. Many modern aircraft are equipped with true airspeed indicators that require no corrections.

We need TAS to determine the groundspeed (GS) or the speed that we are moving over the ground. How we find GS using TAS is explained later.

ALTIMETER

The **altimeter** measures **altitude**, the vertical distance above a level plane of reference, such as sea level. Because the altimeter gives altitude information, it is one of the most important instruments in an airplane. Most light planes use an aneroid barometer as an altimeter. It measures the atmospheric pressure at flight level, that is, the weight of the air above the craft. As previously noted in another section, air pressure (or air weight) decreases as altitude increases. As air pressure around the altimeter's sealed diaphragm decreases, the diaphragm expands.

When the airplane returns to a lower altitude and the atmospheric pressure increases, the diaphragm contracts. The results of this expansion and contraction are transmitted by levers and gears to indicator hands on the dial of the altimeter. The pressure altitude is shown on the dial as feet above sea level.

There are many types of altimeters in use today. One of the most common altimeters has a dial face graduated with numerals from 0 through 9. The three pointers on the face of the altimeter each represent different altitude measurements. The 100-foot indicator makes one complete revolution for each 1,000 feet of altitude. Each numerical reading is made in hundreds of feet, for this pointer.

The intermediate, or second pointer, makes one full revolution for each 10,000 feet of change in altitude. This scale is then read in thousands of feet. The third pointer reads in tens of thousands, and one revolution represents 100,000 feet. This is illustrated in Figure 40, where the altitude displayed is 9,570 feet. The cross-hatched "Low Altitude Warning Symbol" slowly decreases as the aircraft climbs, and it disappears as the aircraft passes through 14,000 feet. Another example of altimeters is shown in Figure 41.

With an increase in altitude, the altimeter will give readings that are not exactly correct. To obtain exact readings, the indicated reading must be corrected for atmospheric pressure, temperature, and instrument error.

To achieve vertical clearance, all aircraft in a given area are given a particular pressure level known as an altimeter setting. Altimeter settings may be generally defined as the pressure reduced to sea level in inches of mercury for a given reporting station. Prior to takeoff, the pilot should set the altimeter with the correct altimeter setting. This setting is furnished by the tower and is set on the barometric scale of his altimeter.

Setting the altimeter results in a reading of indicated altitude. Flying at an indicated altitude insures traffic separation, since

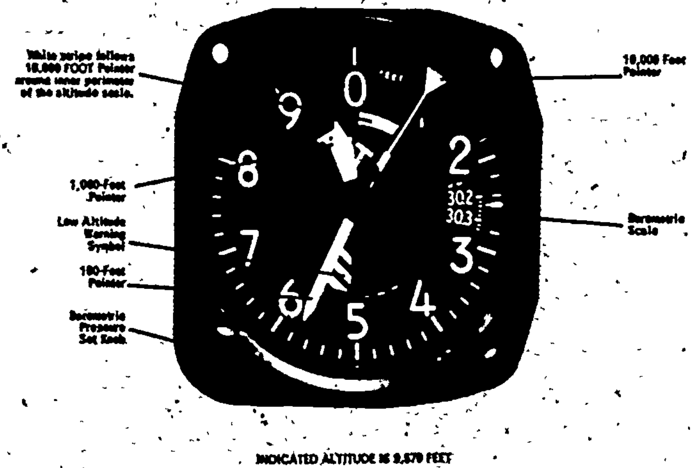


Figure 40. Three-Pointer Altimeter.

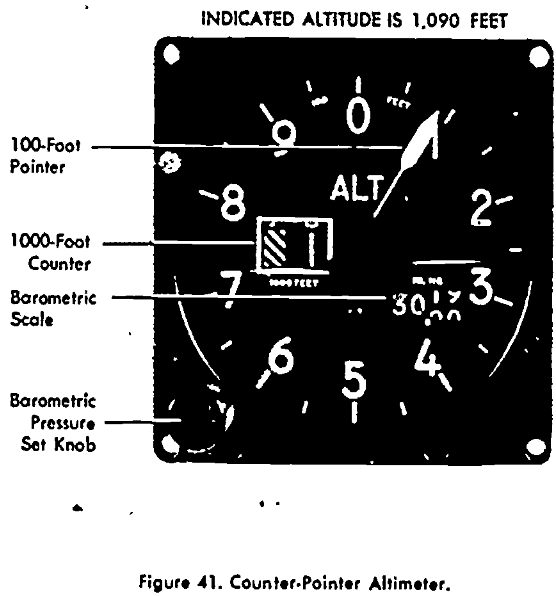


Figure 41. Counter-Pointer Altimeter.

all properly set altimeters in the area are equally affected by whatever pressure and temperature conditions may exist. Pilots need not make allowance for nonstandard atmospheric conditions but must keep their altimeters adjusted to the latest altimeter setting These settings can be obtained from radio stations or control towers along the route.

If no means were available to change the altimeter setting, flight would be extremely hazardous, especially over mountainous areas A change of $\frac{1}{10}$ of an inch of mercury in the pressure setting will result in a change of 100 feet in altitude. If there is a change of one inch in the pressure setting, the altimeter reading will be changed by 1,000 feet. While flying along a flight path, the pilot must set his altimeter to the readings given by the nearest stations. At higher altitudes above 18,000 ft, everyone uses an altimeter setting of 29.92. The altimeter can be one of the most important of the navigational instruments, and every pilot must understand its restrictions. Careful usage coupled with periodic checks are necessary.

TYPES OF ALTITUDE

Pilots are usually concerned with five different types of altitude (Fig 42):

Absolute altitude: height of an aircraft above the terrain over which it is flying.

Indicated altitude: uncorrected altitude read directly from the altimeter after it has been set at the current altimeter setting.

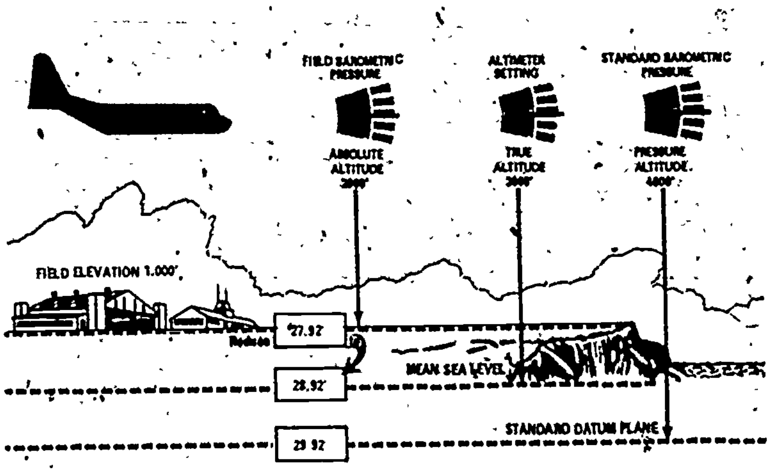


Figure 42, Types of Altitude.

Pressure altitude: altitude read from the altimeter when the setting is adjusted to 29.92; used to compute density altitude, true airspeed, true altitude, etc.

Density altitude: the pressure altitude corrected for temperature variations; important because it is directly related to aircraft takeoff and climb performance.

True altitude: actual height above sea level of an aircraft; the actual altitude, usually expressed as MSL, for example, "9,500 feet MSL"; **MSL** is **mean sea level.** Airport, terrain, and obstacle elevations are stated in terms of true altitudes.

COMPASS

A **compass** is an instrument that indicates direction. Two basic types of compasses are currently used.

The **magnetic compass** uses as a reference the lines of force of the earth's magnetic field. Even though the earth's field is usually distorted by the presence of other local magnetic fields, the magnetic compass has been the most widely used.

The gyrocompass uses an arbitrary fixed point in space determined by the initial alignment of the gyroscope axis. Compasses of this type are widely used today.

The magnetic compass is reliable, and it will give good navigational results if used carefully. Even modern aircraft have a magnetic compass that is used as a standby compass in case of failure of the electrical system required for the operation of the gyrocompass. There are two parts of the magnetic compass that are important to us: the compass card and the lubber line.

The **compass card** (Fig 43) is mounted in a bowl filled with fluid. This fluid partially floats the card, taking some of the weight off the pivot that supports it. Magnets mounted on the card remain aligned with magnetic north as the aircraft turns. A compass rose, graduated in one-degree intervals on some models and in five-degree intervals on others, is attached to the card. The compass is read through a glass window. Down the center of the window is a **lubber line** where the heading is indicated.

Concealed in the compass on the opposite side from the window is an expansion-contraction cell that provides for expansion and contraction of the liquid caused by changing temperatures. On top of the compass case are two small magnets that can be rotated to adjust the compass.

In solving the direction element of the navigation problem, we work with course, heading, and track. When working with a magnetic compass, we are concerned with three kinds of headings. true heading, magnetic heading, and compass heading.

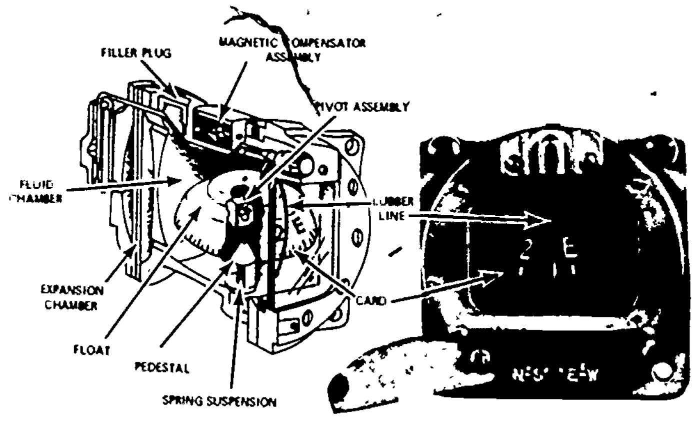


Figure 43. Magnetic Compass.

True heading (TH) is the direction of the aircraft in relation to geographic north. Unfortunately, compasses do not use geographic north as their reference. The actual reference of compasses is a point offset from north called **magnetic north.** This difference

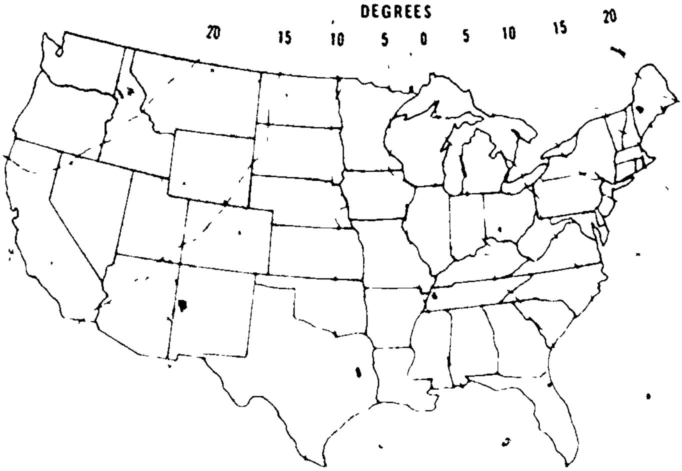


Figure 44 Isogonic Lines connect points with the same Variation

between the two references is called **variation (VAR).** Variation has been measured at a great many places throughout the world, and the values have been plotted on charts. A line may be drawn through all points with the same variation. Such lines are called **Isogonic lines** (Fig. 44).

Isogonic lines are printed on navigation charts. If you know your approximate position, you can determine the amount of variation for your flight. Variation is listed on charts as east or west. When variation is east, magnetic north is east of true north. Similarly, when variation is west, magnetic north is west of true north. Magnetic variation must be applied to a compass heading to obtain a true heading.

Another error to be corrected is deviation. **Deviation** is caused by nearby magnetic influences, such as those related to magnetic material in the structure of the aircraft and its electrical systems. For this reason, deviation is different and must be determined for each aircraft. The process of determining deviation is known as a **compass swing.** Deviation is different for every heading.

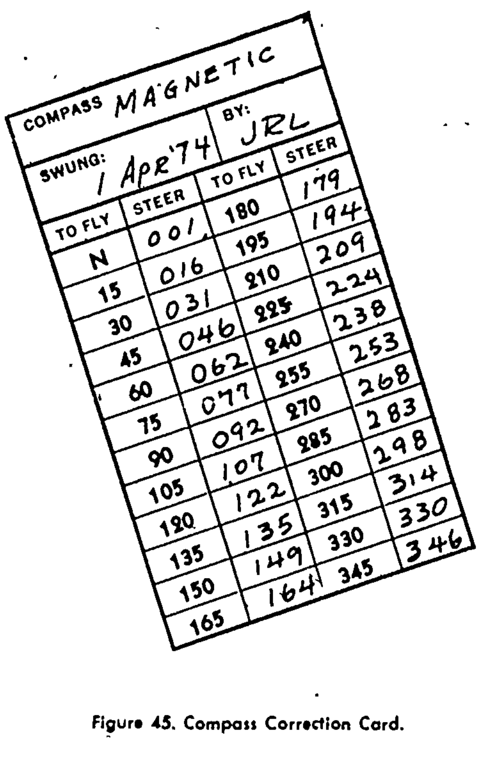


Figure 45. Compass Correction Card.

Deviation is labeled east and west, and it is also recorded on a compass correction card (Fig 45) usually mounted near the compass to which it refers. From the example shown, we know that, to fly a magnetic heading of 090, we must steer 092.

The corrections for variation and deviation are expressed as plus or minus values and are computed as corrections to true heading. If variation or deviation is east, the sign of the correction is minus, and if west, the sign is plus. There is an easy way to remember this. There once was an ancient ship captain who was renowned as the world's greatest navigator. He had one mysterious quirk, however. He always carried a little black box, and, every once in a while, he would peek into it. No one else was ever allowed to see the contents of the box. One day, the great navigator died, and, while going through his personal effects, his crew came across his little black box. The temptation was too great, and they opened the box and peered inside. There was written, "Oriens Est Minimus, et Occidens Est Maximus," **(East is least and West is best).** Subtract east variation and deviation and add west. It since has become the navigator's motto.

Magnetic heading (MH) differs from true heading by the amount of variation. **Compass heading (CH)** differs from true heading by the amount of variation and deviation (Fig 46).

Most pilots express these relationships on some type of log. Thus, if an aircraft is flying in an area where the variation is 10°E and the compass has a deviation of 3°E, the relationship would be expressed as follows for a true heading of 138°:

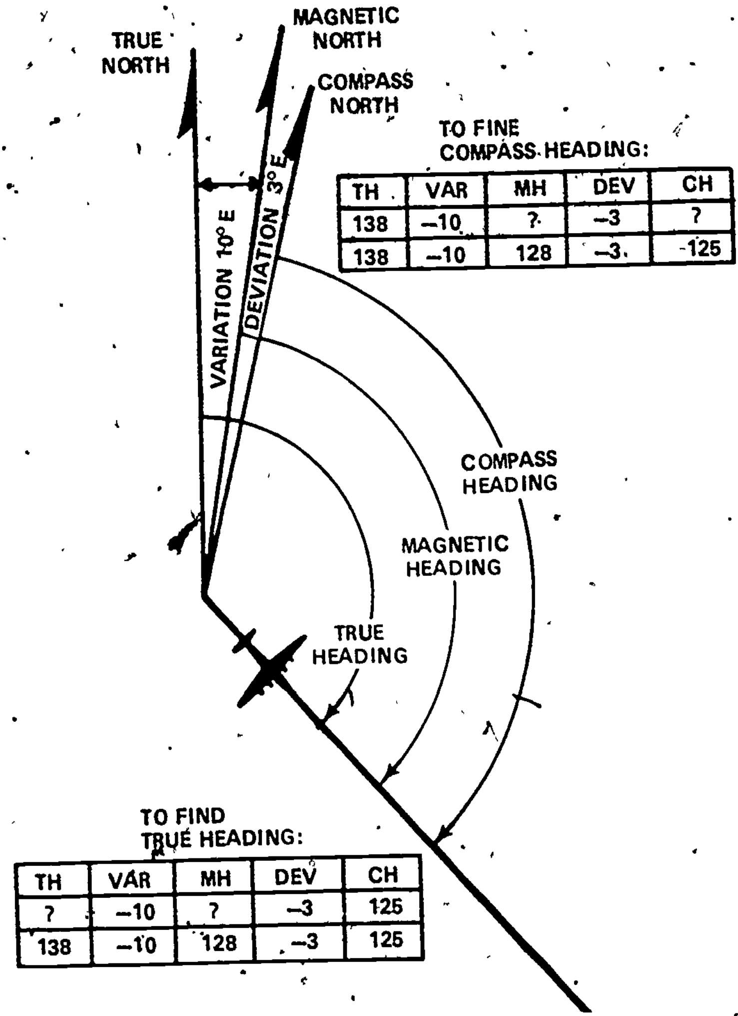
TH		VAR		MH	DEV		CH
138	−	10	=	128	−3	=	?

The compass heading would be 125°. If you have a CH = 130 in the same aircraft and in the same area, the problem would be as follows:

TH	VAR	MH	DEV	CH
?	−10	133	−3	130

The TH would be 143°. The clue is to remember that the corrections are applied from left to right. If you start on the right, the corrections are reversed.

Unfortunately, variation and deviation are not the only errors of a magnetic compass. Additional errors, such as northerly turning error and speed error, are caused by the motion of the aircraft. If you start flying, these errors will be introduced, and you will be shown how to compensate for them.



TO FINE COMPASS HEADING:

TH	VAR	MH	DEV	CH
138	–10	?	–3	?
138	–10	128	–3	125

TO FIND TRUE HEADING:

TH	VAR	MH	DEV	CH
?	–10	?	–3	125
138	–10	128	–3	125

Figure 46. Headings.

To overcome the motion errors and the deviation error, the **gyrocompass** was developed and is used extensively. The deviation error is overcome by placing the compass direction sensing mechanism outside the magnetic fields created by electrical circuits in the aircraft, such as the outer edge of the wing. Indicators for the compass system can then be placed in the aircraft.

Since this compass is gyrostabilized, all errors induced by aircraft motion are eliminated. Since deviation is eliminated, the CH and MH are equal. Therefore, only variation has to be applied to TH to get CH.

WORDS AND PHRASES TO REMEMBER

attitude indicator
turn-and-bank indicator
airspeed
groundspeed
pitot tube
indicated airspeed (IAS)
calibrated airspeed (CAS)
true airspeed (TAS)
altimeter
altitude
absolute altitude
indicated altitude
pressure altitude
density altitude
true altitude
MSL
compass
magnetic compass
compass card
lubber line
true heading (TH)
magnetic north
variation (VAR)
Isogonic lines
deviation
compass swing
"East is least and West is best"
magnetic heading (MH)
compass heading (CH)
gyrocompass

QUESTIONS

1. Name the four basic instruments needed for elementary navigation.
2. What do instruments do?
3. Another name for the needle and ball is ______________ indicator.
4. True or False. The FAA requires that private pilots be able to control aircraft altitude by instruments alone.
5. True or False. Fuel consumption is figured in miles-per-gallon.
6. List the four components of the airspeed indicator system.
7. Explain how airspeed is measured.
8. Name three things that induce error in the airspeed indicator.
9. True or False. Calibrated airspeed is airspeed read directly off the indicator with no correction applied.
10. The greatest potential for airspeed error occurs at (low, high) airspeeds.
11. True or False. TAS is most accurate when found by using a computer.
12. True airspeed (increases/decreases) with an increase in altitude.

13. Using one of the shorthand methods of figuring true airspeed, find the approximate true airspeeds:

Altitude	IAS	TAS
3000′	100K	______
4500′	110K	______
5000′	120K	______
6000′	140K	______

14. Most altimeters in light airplanes are an ________________ apparatus.

15. Altimeters in most light aircraft measure the weight of the air (above/below) the aircraft.

16. The altimeter cross-hatch ______________________ as the aircraft descends.
a. remains constant
b. disappears
c. gets larger
d. gets smaller

17. Name three corrections that need to be made to obtain exact altimeter readings.

18. The altimeter setting is set on the ____________________ scale.

19. True or False. Every aircraft flying in a local area should have the same altimeter setting.

20. A change from an altimeter setting of 29.92 to a setting of 30.02 will result in a change of ___________ feet in altitude.

21. 10,000 feet MSL is an example of
a. absolute altitude
b. true altitude
c. indicated altitude
d. density altitude

22. What are the two basic types of compasses in use? How do they differ?

23. What two parts of a magnetic compass are we most concerned with?

24. Explain the parts of a magnetic compass.

25. Name three kinds of headings and explain how they differ.

26. If you are one-half way between the isogonic lines 4°E and 0°, what is your variation correction?

27. Solve for the following headings:

TH	VAR	MH	DEV	CH
_____	6E	_____	−1	123
235	1W	_____	+4	_____
000	21E	_____	+1	_____
_____	6W	_____	−3	180

28. How is deviation compensated for in a gyrocompass system?

29. With a gyrocompass, CH equals ____________________.

THINGS TO DO

1. Get a chart of the common aircraft instrument panel and identify the different instruments and their use.

2. Try to get a cutaway of the various instruments showing the actions of the instrument diaphragms and other apparatus. Report to the class, by demonstration, how each of these instruments works.

3. Go to a local airport and ask how they swing compasses. See if you can be available to help with a compass swing. Report to the class on the procedures.

4. Go to the nearest weather station, either military or FAA, and find out how they figure the local altimeter setting. Report to the class on how this is accomplished.

SUGGESTIONS FOR FURTHER READING

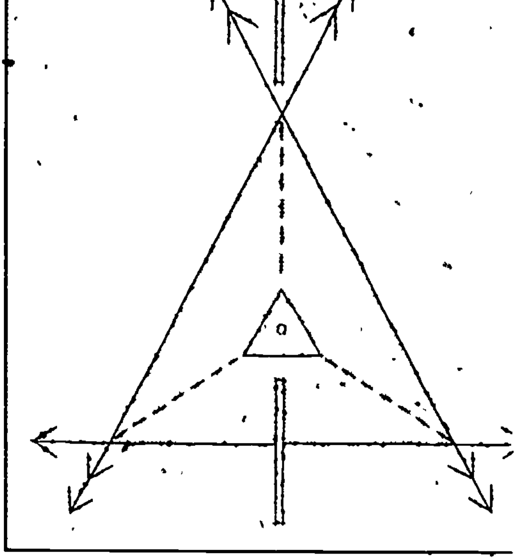
US Air Force AFM 51-37, *Instrument Flying*, Washington, DC, Department of the Air Force, 1971.

US Air Force AFM 51-40, *Air Navigation*, Vol 1, Washington, DC, Department of the Air Force, 1968.

LYON, THOBURN C., *Practical Air Navigation*, Denver, Colorado. Jeppeson, 1972.

SANDERSON, *Aviation Fundamentals*, Denver, Colorado. Sanderson, 1972.

Chapter 6



Dead Reckoning

IN THIS CHAPTER, you study the fundamentals of navigation. These fundamentals, or basic methods, are called dead reckoning (DR) procedures. This is an especially important chapter since some elements of dead reckoning are used on every flight. After studying this chapter, you should be able to: (1) understand the elements of dead reckoning used in preflight planning and in flight navigation, (2) figure true course and track, and (3) understand the wind triangle and its application.

THERE IS A STORY that ancient mariners told new sailors aspiring to be navigators. In warning young lads of the horrible things that could happen if the ship got lost, old salts would say, "If you don't reckon' right, you're gonna be dead." Some people claim that this was the origin of the term dead reckoning.

Dead reckoning (DR) is the basic method of navigation. In reality, the term did come from the early mariners, but the origin of the term came from the ship's log book. Navigators of old deduced their positions at any given time by using the distances and directions that their vessels had gone since passing or leaving a known position. Such positions were determined at frequent intervals and were entered in the ship's log book under a column headed by the abbreviation "ded. pos.," for "deducted position." The reckoning necessary to obtain the information for these entries was known as "ded reckoning." Over the years, through popular usage, "ded reckoning" became "dead reckoning."

The major idea behind dead reckoning navigation is to know, by preflight planning and inflight checking, the position of the aircraft at any given time. DR navigation enables the pilot or navigator to determine the position of his aircraft and to direct it from place to place. He accomplishes this by measuring or calculating and keeping account of navigational factors, such as direction, distance, time, wind, and speed. By using his flight plan, a pilot may glance at his information and determine how the flight is progressing.

It is possible, using only the basic instruments explained in the previous chapter, to navigate directly to any place in the world. However, navigation is only as accurate as the information available. Instruments are not always exact, corrections figured on the ground aren't exactly true in the air, and, even though most pilots find it hard to admit, their ability to hold exact airspeeds, altitudes, and headings is not always perfect. For this reason, the result of DR should not be considered an exact point but a probable position from which you can start using some other navigational aids. Therefore, such things as celestial, radar, LORAN, pilotage, etc, should be considered as navigation aids. These aids are known primarily as fixing aids, and they provide information from which winds, groundspeeds, and alterations to the path of the aircraft can be computed. Proficiency in DR procedures is indispensable if full use is made of these aids to navigation.

The factors that are used in DR include:

1. True course (TC)
2. True airspeed (TAS)
3. Wind direction (W)
4. Wind velocity (V)
5. True heading (TH)
6. Groundspeed (GS)

To understand how these are derived and put to use, we must understand the wind triangle. Any vehicle traveling on the ground moves in the direction in which it is steered or headed. Ground vehicles are affected very little by wind. An aircraft, on the other hand, seldom travels in exactly the direction in which it is headed. This is caused by the wind effect.

The horizontal motion of air over the earth's surface is called wind. **Wind direction (W)** is the direction from which wind moves.

Thus, a wind that blows from the south toward the north has a direction of 180°. The **wind velocity (V)** is stated in knots. Whenever a wind is reported, the wind direction and velocity are combined and reported as a **W/V**. For example, a wind from the west blowing east at 20k is reported as W/V, 270°/20k.

Consider the effect of wind on a balloon that has no propulsion of its own. In Figure 47, a balloon is launched at point A at 0900. If the wind is 270°/20k, where is the balloon at 1000? Think of the balloon as floating in a body of air that moves from 270° toward 90° at 20k. In one hour, the body of air moves 20nm, and the balloon moves with it. Thus, in the illustration, at 1000, the balloon reaches point B, 20nm from point A in the direction of 90°. A balloonist never feels any wind because he is suspended in the body of air and moves with it. Consequently, no air moves past him. A balloon in the air is like an empty bottle floating down a river, it travels with the current.

Any free object in the air moves downwind with the speed of the wind. This is just as true of an aircraft as it is of a balloon. If

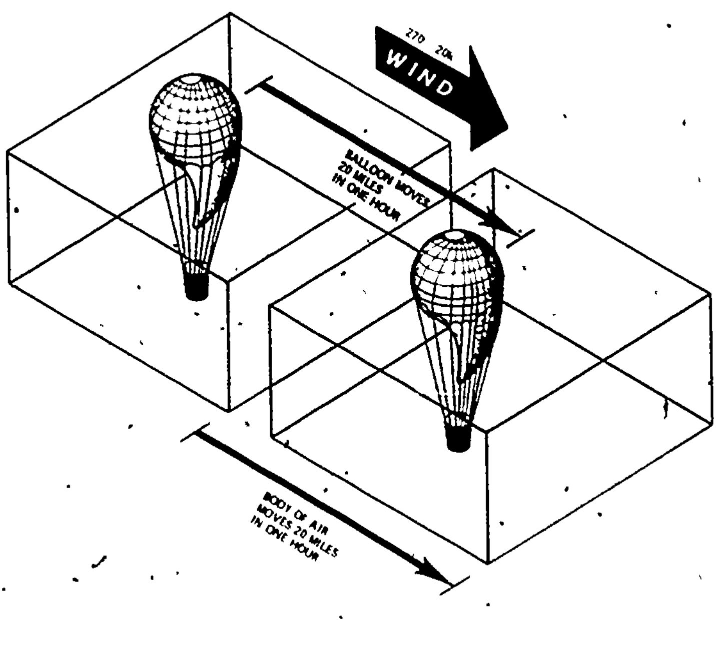


Figure 47 Balloon Floats Downwind at rate equal to Wind Speed

an aircraft is flying in a 20k wind, the body of air in which it is flying moves 20nm in one hour. Therefore, the aircraft also moves 20nm downwind in one hour. This movement occurs in addition to the forward movement of the aircraft through the body of air.

The path of an aircraft over the earth is determined by two factors: (1) the motion of the aircraft through the air mass and (2) the motion of the air mass across the earth's surface. The motion of the aircraft through the air mass is directly forward in response to the pull of the propellers or thrust of the jets. The rate of forward movement is true airspeed (TAS). The motion takes place in the direction of true heading (TH). The motion of the air mass is the wind.

An aircraft's movement over the ground is comparable to a boat crossing a river. If the river has no current, a boat started at one shore of the river and rowed directly across the river would reach a point on the opposite shore directly across from its starting point. However, if there is a current, the boat will be carried downstream (Fig 48). Until the boat eventually reaches the opposite shore, the displacement downstream depends on the **velocity** or speed and direction of the current. Another factor affecting the point of landing is the speed of the boat.

The aircraft in Figure 49 departs from point A on a heading of 360° and flies for one hour in a wind of 270°20k. The aircraft is headed toward point B, directly north of A. If there were no wind, the aircraft would be at point B at the end of the hour. However, there is a wind. The body of air in which the aircraft is flying moves 20nm toward the east during the hour, and

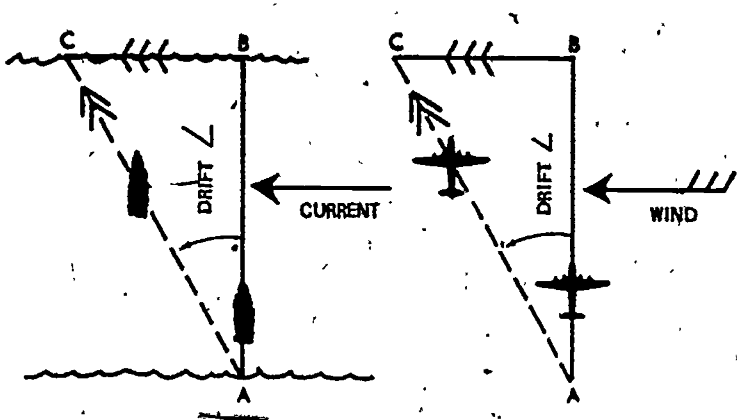


Figure 48 River current affects a boat the same as wind affects an aircraft

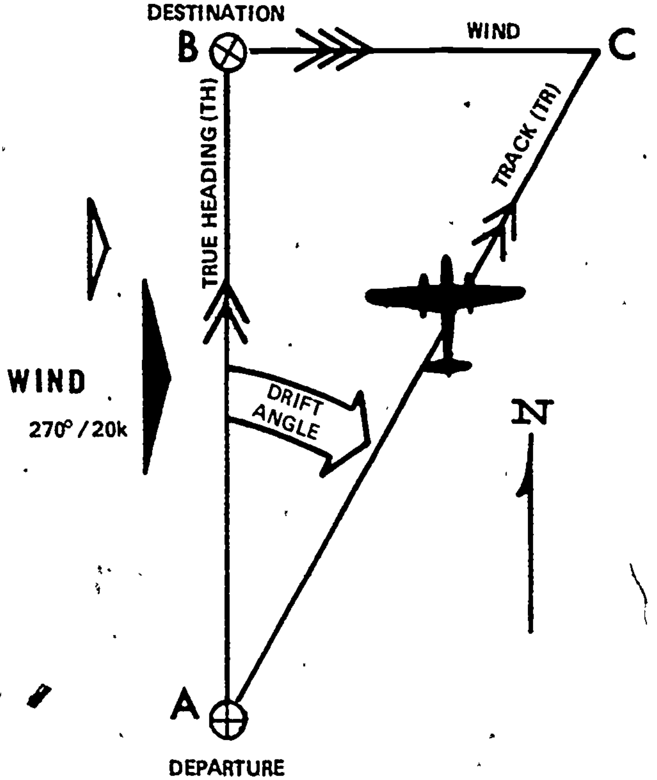


Figure 49 In One Hour, Aircraft Drifts Downwind and Amounts Equal to Wind Speed.

the aircraft moves with it. Consequently, at the end of the hour, the aircraft is located at point C, 20nm downwind from point B. The line AB is the path of the aircraft through the body of air, the line BC shows the motion of the body of air, and the line AC is the actual path of the aircraft over the earth. Lines AB, BC, and AC are **vectors**, of lines, that show speed by the length of the line and direction by the orientation of the line. The navigation symbols used for each of these vectors are shown in Figure 50

The path over the ground is **track (TR)**. In Chapter 3, we learned that the true course (TC) is the intended path of the aircraft over the earth's surface Track is the actual path that the

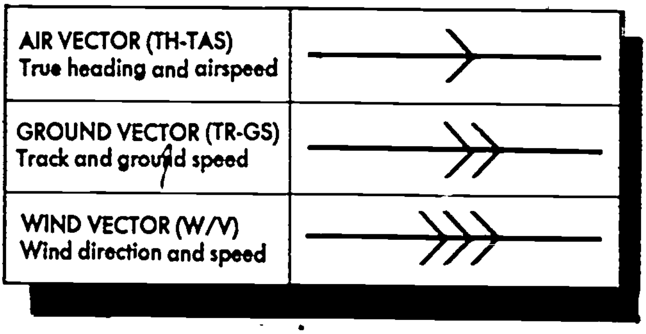


Figure 50. Standard Plotting Symbols for Vectors.

aircraft has flown over the earth's surface. TC is future and TR is past.

The difference between TR or TC and true heading (TH) is the displacement of the aircraft caused by the wind. This displacement is called **drift.** It is expressed as the angle between TH and TR. When an aircraft drifts right, the drift is referred to as right drift.

Any given wind will cause a different drift for every heading. For example, if an aircraft were flying a heading of 360° and maintaining a TAS of 120k, it would have a right drift of 9° with the 270°/20k wind. If the aircraft turned to a heading of 120°, the drift would decrease to approximately 4° and would be left drift.

A change of heading will also affect the distance flown over the earth's surface in a given time. With a given wind, the groundspeed (GS) varies on different headings. Using the same problem as before, TH 360°, TAS 120k, W/V 270°/20k, the GS is 122k. When we turn to a heading of 120°, the GS increases to about 138k. Figure 51 shows the effect of a 270°/20k wind on the GS and TR of an aircraft flying THs of 000°, 090°, 180°, and 270°

We have now seen how wind affects an aircraft in flight. In attempting to fly from point A to point B, we could let the wind drift us to point C and turn into the wind to fly to our destination B. This is not very practical, since it would extend our flight unnecessarily.

The simplest way to correct for wind is to head the aircraft upwind to maintain the TC. This is called correcting for drift or

drift correction. The angle BAC in Figure 52 is the correction that is applied to a TC to find the TH.

The amount of drift correction must be enough to compensate for the amount of drift on the particular heading. The drift correction angle must be equal to the drift angle. If drift is made to the right, drift correction must be made to the left or minus. The drift correction angle is measured in the opposite direction of the drift and given a sign of plus or minus. Keep in mind that the compass rose increases clockwise, or to the right.

Figure 53 shows the drift correction necessary in a 270°20k wind if the aircraft is to make good a TC of 000°, 090°, 180°, or 270°. Note that, to reach point B or D, the aircraft need make no drift correction. To reach point A or C, the aircraft must head upwind. This means that, to reach point A, the aircraft must correct to the left or apply a minus (−) drift correction, and, to reach point C, it must correct to the right or apply a plus (+) drift correction. To find the TH to make good a TC, you must compute a drift correction and apply it to TC (TC ± drift correction = TH).

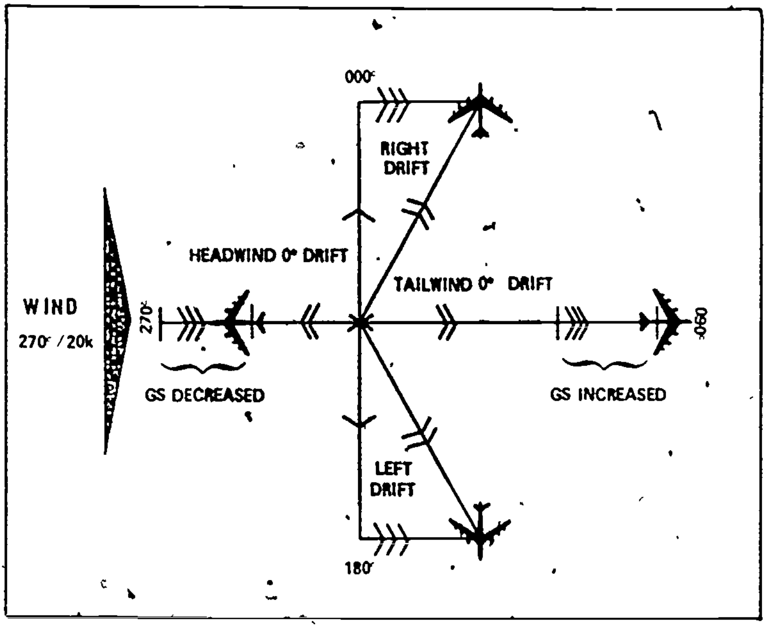


Figure 51 Effect of Wind on Aircraft flying in Opposite Directions

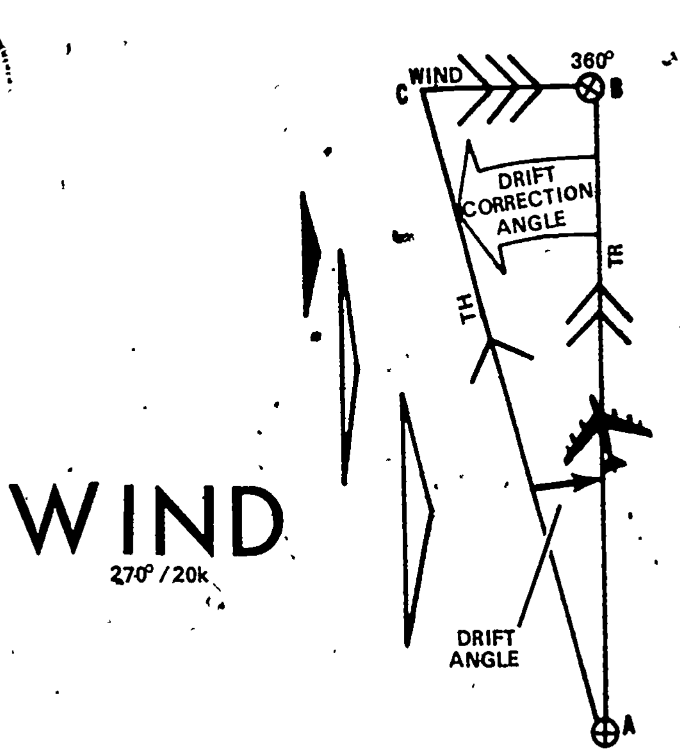


Figure 52. Aircraft Heads Upwind to Correct for Drift

When the drift is left, correct to the right, and the sign of the correction is plus. When the drift is right, correct to the left and the sign of correction is minus.

WIND TRIANGLE

We need not let the wind carry us where it will. We have found that, by turning upwind, we can correct for the wind's effect on the aircraft. This is fine, but we also must find a method of determining the appropriate correction required for us to reach our destination. One method of doing this is to use the wind triangle and vector solution methods. For example, TH, TAS, and W/V may be known, but we need to find TR and GS.

The vector displaying either TAS and TH, TR and GS, or W/V can be drawn on paper as a straight line. The direction of this line is the angle measured clockwise from true north. The length of the line shows the magnitude or speed of TAS, GS, and V. Arrowheads should be ~~drawn on~~ the line to avoid any misunderstanding of its direction (Fig 54).

Two or more vectors can be added together by placing the tail of each succeeding vector at the head of the previous vector. These vectors are known as **component vectors.** The sum of the component vectors can be determined by connecting, with a straight line, the tail of one vector to the head of the other. This sum is known as the **resultant vector.** By its construction, the resultant vector forms a closed figure as shown in Figure 55. Notice that the resultant is the same regardless of the order as long as the tail of one vector is connected to the head of the other.

A vector illustration showing the effect of the wind on the flight of an aircraft is called a **wind triangle.** To develop the wind triangle, we use three vectors. the air vector, the wind vector, and the ground vector.

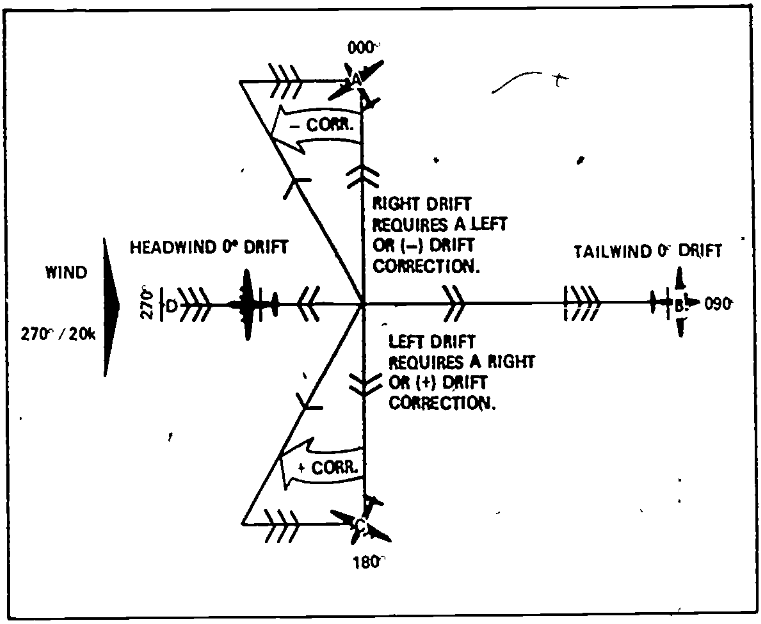


Figure 53 Maintaining Course in Wind

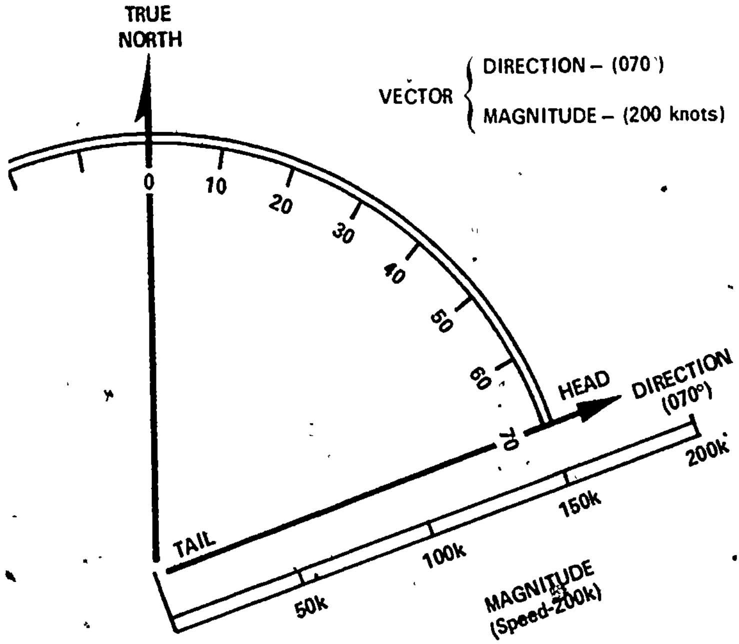


Figure 54. A Vector has both Magnitude and Direction

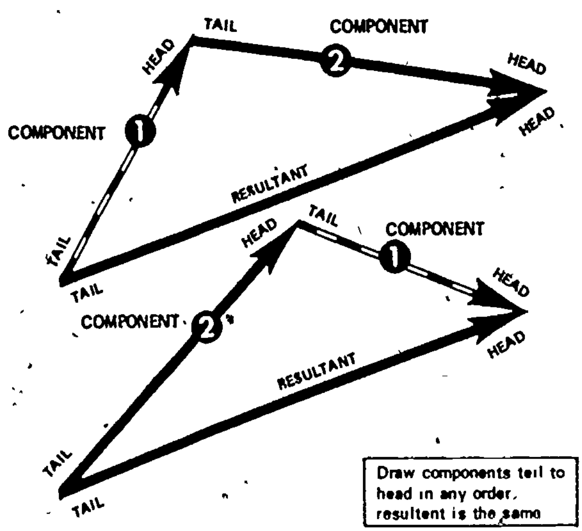


Figure 55 Resultant Vector is Sum of Component Vectors

The air vector is made up of TH and TAS. The **wind vector** is WV. It is connected to the air vector so that the tail of the wind vector is attached to the head of the air vector. A line connecting the tail of the air vector with the head of the wind vector is the resultant of the two component vectors. This resultant is the **ground vector,** and it depicts TR and GS. You must use the same scale to show GS, V, and TAS. Remember that the wind always blows the aircraft from TH to TR.

Consider what the wind triangle shows. In Figure 56, an aircraft departs from point A on the TH of 360° at a TAS of 150k. In one hour, if there is no wind, it reaches a point B at a distance of 150 nm. Line AB shows the direction and distance that the aircraft has flown. The length of AB shows the TAS of the aircraft. Thus, AB represents the velocity of the aircraft through the air, and it is the air vector.

Suppose the wind were blowing from 270° at 30k. We then draw the wind vector (using W/V) from the head of the air vector. The length BC represents the speed of the wind drawn to the same scale as the TAS.

The line AC is the ground vector, which is the result of the wind blowing on the aircraft as it flew its TH and TAS for a one-hour period. The length of AC represents the groundspeed drawn to the same scale as the TAS and wind speed. The line AC is the resultant of AB and BC.

Measuring the length of AC determines that the GS is 153k. Measuring the drift angle, BAC, and applying it to the TH of 360° results in the TR of 011°.

If two vectors in a wind triangle are known, the third one can be found by drawing a diagram and measuring the parts. For instance, suppose that, after flying for one hour, we know that we have maintained a TH of 360° and TAS of 150k. Through pilotage, we know that, in this same period, we had made good a TR of 011° and GS of 153k. By drawing these two vectors and making sure that their tails are connected, we can find the WV. All that we need to do is to measure the remaining vector, and the result will be W/V.

The wind triangle includes six things. three speeds and three directions. Problems involving these six quantities make up the major part of dead reckoning navigation.

There are three methods of solving the wind triangle. It may be solved by trigonometric tables, however, the accuracy of this

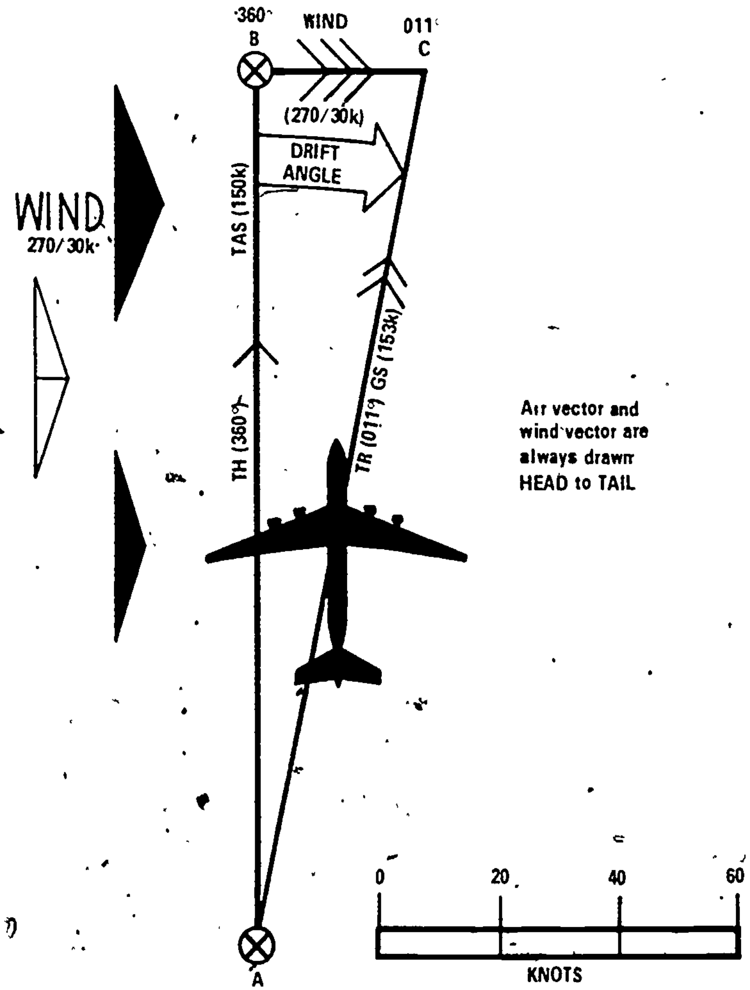


Figure 56. Wind Triangle

method far exceeds the accuracy of the data available and of the results needed. We have already studied a second method of solving the wind triangle. We used a chart to draw two vectors so that we could measure the vector representing the unknown quantities. A third method is to solve the wind triangle on the wind face of the computer. This method is explained in Appendix B.

WORDS AND PHRASES TO REMEMBER

dead reckoning (DR)
wind direction (W)
wind velocity (V)
W/V
velocity
vector
track (TR)
drift
drift correction
component vectors
resultant vector
wind triangle
air vector
wind vector
ground vector

QUESTIONS

1. The basic method of navigation is ______________ ______________.

2. Dead reckoning is used for:
   a. preflight planning
   b. inflight checking
   c. Both a and b
   d. None of the above

3. True or False. The position obtained from DR should be considered a precise point.

4. Celestial, radar, LORAN, and pilotage are used to:
   a. replace DR
   b. find a known position
   c. update DR position
   d. b and c

5. The six factors used in DR navigation are:
   a. d.
   b. e.
   c. f.

6. Aircraft very seldom travel in the direction they are headed because of ____________ ____________.

7. A wind vector is plotted (to/from) the direction it moves.

8. An object flying in a wind moves (downwind/upwind).

9. Draw the symbols used to depict the following vectors:
   a. Air vector
   b. Ground vector
   c. Wind vector

10. True or False. A wind of 180°/60k will affect an aircraft on a TH of 090° differently than an aircraft on a heading of 180°.

11. Given: W/V 345/30k. Find the GS of an aircraft flying a TAS of 120K for headings of 345° and 165°.

12. Drift ____________ = Drift Angle.

13. **Solve the following:**

Drift	**Drift Correction**
9° Right	**+3°**
______ ______	________
4° Left	**−6°**

____

14. **Fill in the blanks by referring to what you have learned in chapters 5 and 6.**
_________ ± **Drift Correction** = _________
± **Var** = _________

15. **The length of a vector depicts _________________.**

16. **A wind triangle is made up of three vectors. What are they? What are the components of each?**

17. **In a wind vector, the tail of the wind vector is connected to the _____ _______ of the air vector. The tail of the ground vector is connected to the _________ of the wind vector. The ____________ of the air vector is connected to the ____________ of the ground vector.**

18. **True or False. All speeds or magnitudes on a wind triangle must be drawn to the same scale.**

19. **Name three methods of solving the wind triangle.**

THINGS TO DO

1. Construct a wind triangle to find the missing elements:

TH 080	________
TAS 150k	________
TC 070	340
GS 152k	160k
W ______	220
V ______	20k

2. Find a flight log and figure all the headings and speeds for a flight from the closest airport to an airport over 100nm away. Obtain the wind for your altitude from the weather station serving your airport.

3. Using Appendix B, solve the problems in No 1 above by using the com puter wind face. Check how close your answers are.

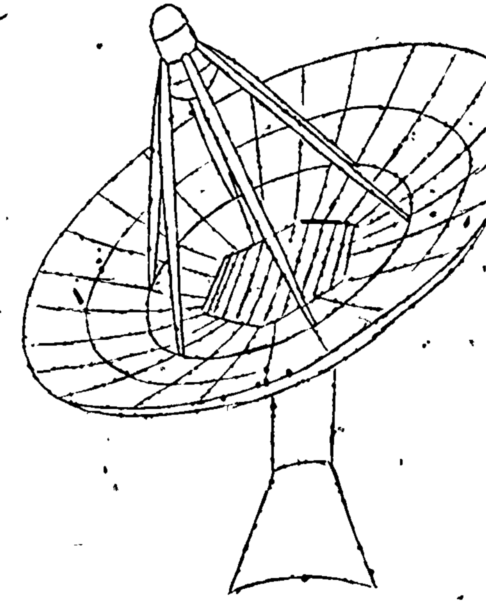
SUGGESTIONS FOR FURTHER READINGS

US Air Force AFM 51–40, *Air Navigation*, Vol 1, Washington, DC. Department of the Air Force, 1968.

CONROY, CHARLES W. and HAROLD E. MEHRENS, *Navigation and the Weather*, Maxwell AFB, Alabama: Civil Air Patrol.

LYON, THOBURN C., *Practical Air Navigation*, Denver, Colorado. Jeppeson, 1972.

Chapter 7



Navigation Aids

THIS CHAPTER is concerned with those navigation aids that help the pilot/navigator to determine his position. This position is then used as the basis to continue the DR problem. You will become familiar with the aids used primarily for light aircraft flying such as VOR, TACAN, VORTAC, ADF, and ILS. You also are introduced to some of the navigation aids used for military and large aircraft flying, such as, celestial, radar, LORAN, doppler, and inertial navigation systems. Upon completion of this chapter, you should: (1) understand the uses of VOR, VORTAC, ADF, and ILS, (2) be familiar with the uses of celestial, radar, LORAN, doppler, and inertial navigation systems, and (3) understand how the navigation aids combine with DR to solve the navigation problem.

Dead Reckoning (DR) is fundamental to navigation. Solving the wind triangle and finding positions based on time, speed, and direction are the foundations of navigation. Unfortunately, DR is seldom exact. When solving the wind triangle problems, we always started from a given point. The assumption is made that the position of this point is known exactly or nearly so. DR always starts from a known position. The longer DR is used from this known position, the less reliable it becomes. Individual small errors can accumulate until the total error becomes dangerously large.

A pilot/navigator employs various means to determine his actual position in relation to the ground. When flying between 4,000 and 10,000 feet on a clear day, we can frequently identify our position by using recognizable landmarks or pilotage. When we identify a position accurately while in flight, the identification is called a **fix.** A fix serves as a new point of departure and cancels previous errors in DR.

Obtaining a fix by pilotage is great as long as the weather is clear or the flight is made at an altitude low enough for you to identify features on the ground. But when this is not the case, we need other methods to obtain an accurate position. Another important reason for understanding other methods of navigation is that backups are needed in the event that a beautiful VFR day turns into a messy batch of clouds and bad weather. One killer of light aircraft pilots is attempted VFR flying into IFR weather.

On the following pages, we cover the most widely used current methods of navigation so that you can at least recognize the methods as you begin to fly. Barely 40 years ago, we were almost totally dependent on pilotage. Now, we use basic navigation concepts to navigate to the moon and beyond.

ADF

The **automatic direction finder (ADF)** receives radio signals from stations, such as radio beacons and commercial AM facilities. ADF equipment indicates the direction of the station being received in relation to the heading of the aircraft. In Figure 57, we see our airplane flying north. The ADF indicates that a station is located 35° (to the right) of our position. In Figure 58, we have turned our aircraft 35°E and are heading directly toward the station. When the ADF needle points to zero, the airplane is flying on course to the tuned station.

The ADF is most often used for **homing.** The pilot tunes in a desired station and then flies directly to that station by keeping the ADF indicating needle on zero. Homing keeps the nose of the aircraft pointing toward the station. For this reason, the ADF has acquired the name **Bird Dog.**

When homing in a crosswind, the airplane will follow a curved course. As the aircraft drifts downwind, the pointer will show that

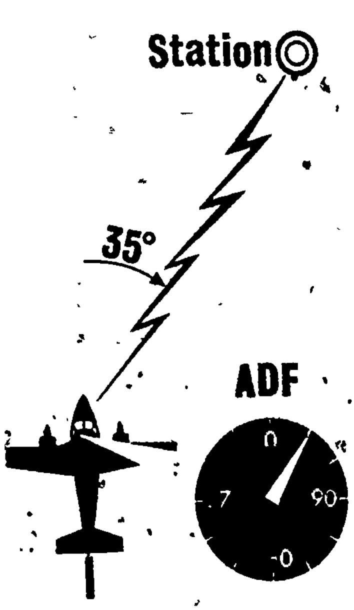


Figure 57. ADF Station 35° Right

Figure 58 ADF Station on Course.

it is not heading directly to the station. Multiple heading changes need to be made to cross the station. When the aircraft passes over the station, the pointer will swing from 000° to 180° (Fig 59).

Figure 60 shows how two kinds of stations used for ADF navigation are depicted on a chart. The radio station WRFS and its frequency are listed next to its tower location. The Alexander radio beacon is displayed by a group of dots with a circle center.

VOR, TACAN, AND VORTAC

Today, the FAA expects all pilots to have a basic knowledge of the **very high frequency omnirange (VOR).** VOR stations comprise the most extensively used radio navigation system for aircraft A VOR station operates in the very high frequency range of 108 0 **MegaHertz (MHz)** to 117.9. MHz A VOR station transmits radio beams in all directions. For this reason, it is sometimes called **omni,** which is short for omni-directional. Figure 61 shows how these radio beams, called radials, extend out from the station like spokes from the hub of a wheel Each beam or radial is identified by its magnetic direction from the station A pilot

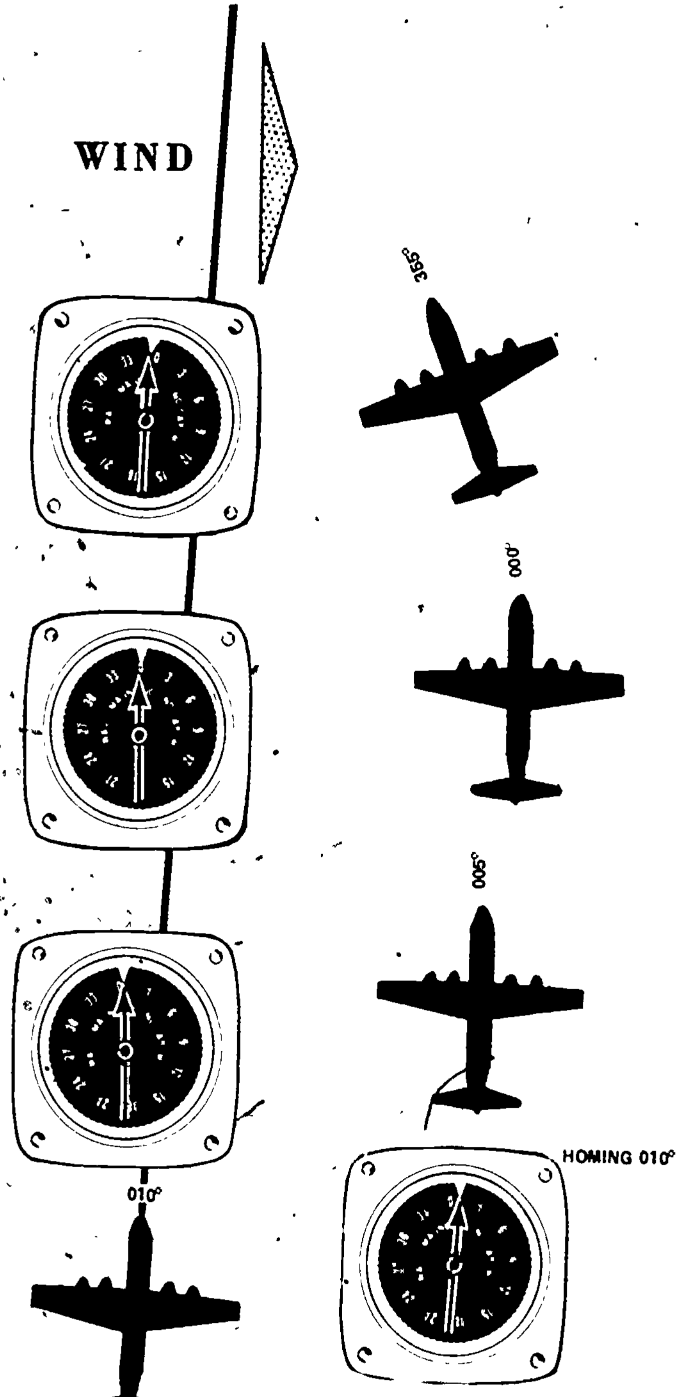


Figure 59 Curved Flight Path as a Result of ADF Homing in a Crosswind

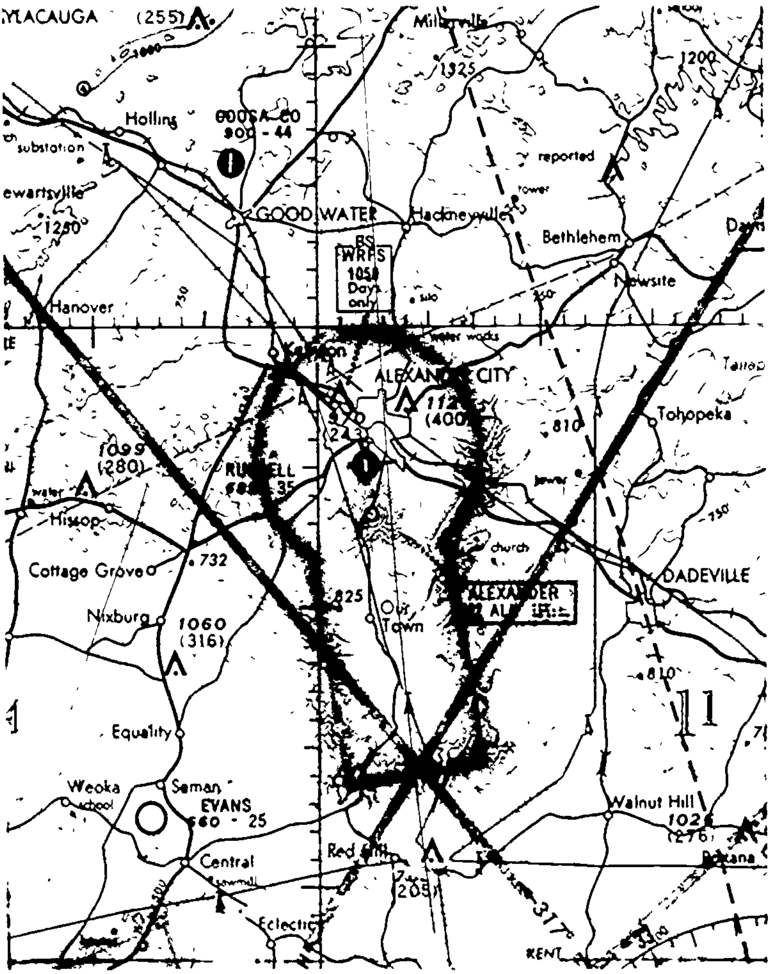


Figure 60 Map Portrayal of two ADF Stations A Commercial AM Station and a Radio Beacon

navigating by VOR may fly to or from a station by following the proper radial, reg. dless of his location

ADF transmissions are subject to weather disturbances, and navigation by them is affected by wind and variation VOR signals, on the other hand, are relatively free of weather disturbance Drift correction and variation do not need to be used because VOR radials provide their own continuous directional guidance

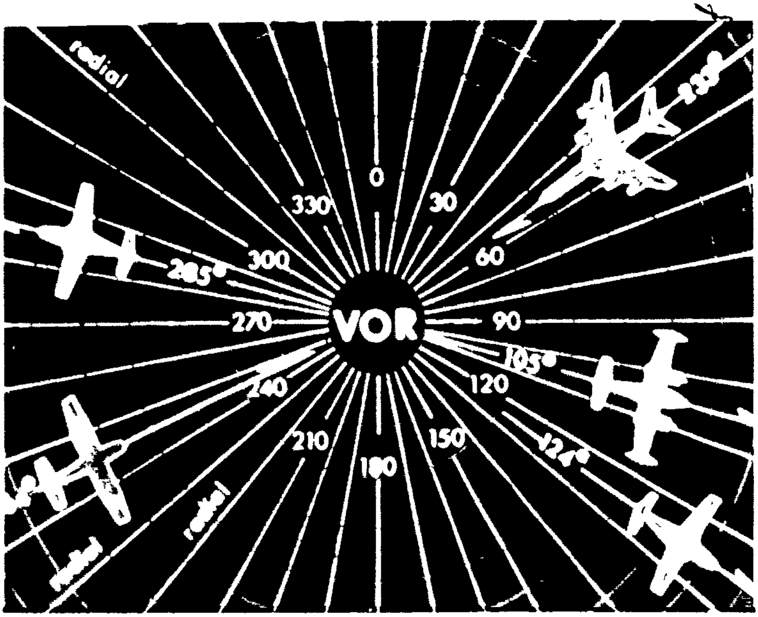


Figure 61 VOR Radials allow for 360 Separate Course Selections

There are two components of the VOR in the cockpit, the control panel and the indicator The control panel usually contains a power switch, frequency selector knobs and indicator, and a volume control Figure 62 shows a military control panel There are many different makes, and it takes a minute or two to become familiar with the controls of each

Figure 63 shows three components of the VOR indicator Each of these gives the pilot information that he needs to navigate by VOR signals The first component, the **course deviation indicator (CDI),** has a vertical needle that swings to the left or right, showing where the aircraft is located in relation to the radial selected on the second component, the **course selector.**

The TO-FROM indicator is the third component of the VOR indicator. This indicator tells the pilot whether the course selected will take the airplane to the station or from the station

Using the VOR to fly to a VOR station is very simple First, you find the frequency and identifier of the station, using either a sectional chart or a special **radio facilities chart** that shows VORs, VORTACs, TACANs, and some ADFs Next, you tune the VOR receiver to the frequency printed on the chart and identify the station by listening to the Morse code identifier or voice identification If you cannot positively identify a VOR station, then

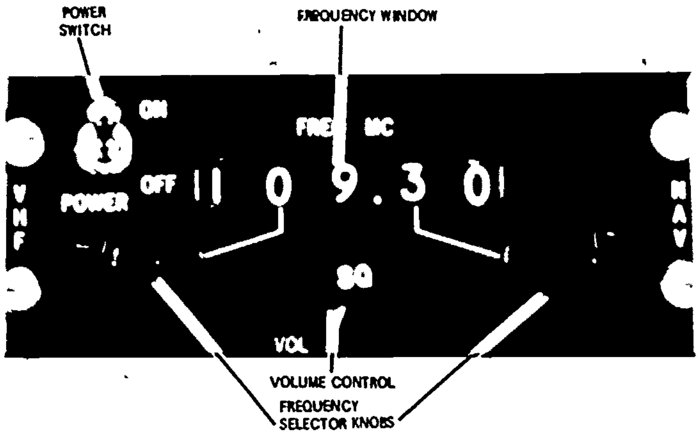


Figure 62 Military VOR Control Panel

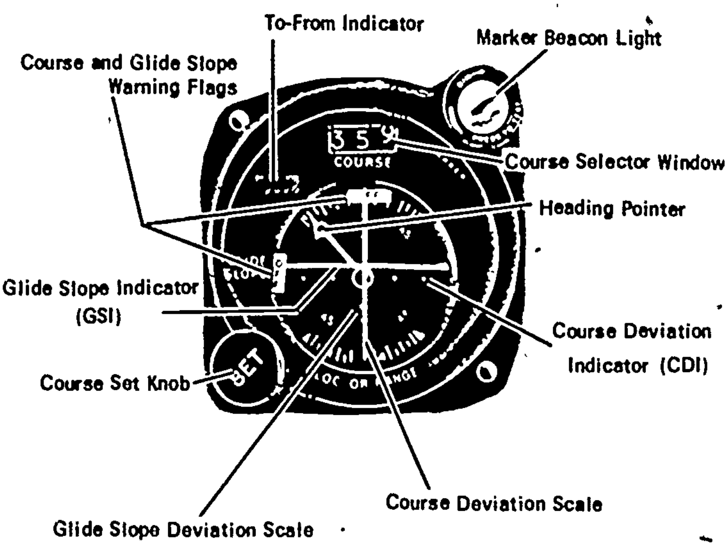


Figure 63 Course Indicator

do not use it for navigation purposes! After identifying the station, turn the course selector until the **TO-FROM indicator** shows TO, keep turning the course selector until the CDI is centered. You now have the magnetic course toward the station on the course selector, turn the airplane until the compass and the course selector are the same. If you keep the CDI centered, the airplane will fly the selected course directly to the station. When the TO-FROM indicator flips from TO to FROM, it is a positive indication that you have passed over the station.

The procedure to fly away from a VOR station is very similar. After tuning the VOR station and identifying it, rotate the course selector to the correct outbound bearing and center the CDI. Make sure that the TO-FROM indicator shows FROM. Turn the aircraft to the compass heading that corresponds to the course indicated by the course selector. If the CDI shows that the aircraft is either left or right of the course, small corrections in heading will return the aircraft to the desired course.

Direction solves only a part of the navigation problem. If the pilot knows his distance from the station in addition to the direction, his navigation can be accurate. For this reason, distance measuring equipment was developed. **Distance measuring equipment (DME)** continuously measures the slant distance of an aircraft from a ground unit located at a known point. The ground unit consists of a combined DME receiver and transmitter. The ground-based system is called a **transponder.** Each aircraft equipped with DME has a unit called an **interrogator.** The interrogater emits a pulse (signal), which is received by the ground-based transponder. The transponder then replies to the interrogator with a similar signal (Fig 64).

The aircraft's DME unit measures the elapsed time between the transmission of the interrogator's signal and the reception of the transponder's reply. This measurement, called the **slant range,** is instantly converted into distance by the airborne unit. The distance in miles is automatically and continuously shown on a dial on the instrument panel.

When DME is used in combination with VOR, a pilot can tell at a glance the direction to a tuned station and the distance to or from it.

Tactical air navigation (TACAN) is a military system of radio-electronic navigation that provides bearing information like VOR and distance information like DME. The need for a common system of bearing and distance information to both military and civilian pilots has resulted in a combination of VOR/DME and TACAN. The combined system is called **VORTAC.**

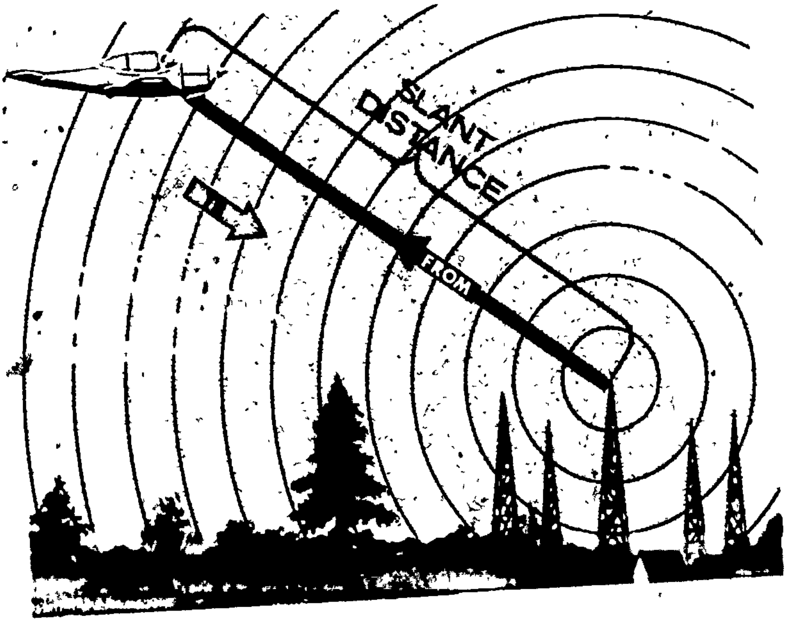


Figure 64. Distance-Measuring Equipment.

If an aircraft is equipped with a complete TACAN unit, the aircraft can receive both directional guidance and distance information from the VORTAC. Aircraft equipped with only VOR may receive directional guidance. If it also has DME equipment, it will receive both directional guidance and distance information. VORTAC stations now comprise the majority of the radio and navigational aids in the United States.

Figure 65 shows how a VORTAC is displayed on a sectional chart. A VORTAC station symbol is shown in blue and is surrounded by an azimuth symbol. This azimuth symbol is adjusted for local variation; therefore, all that is needed to plot a magnetic course is a straightedge. The identification data on the VORTAC is found in a little box within the azimuth symbol. The data noted is the VOR frequency (108.8), the TACAN channel (CH 25), the identifying letters (TDG), and the Morse code for these letters. If the station were only a VOR, there would be no channel given.

ILS

There are other indications on our VOR course indicator. Most of these are concerned with the **instrument landing system (ILS).**

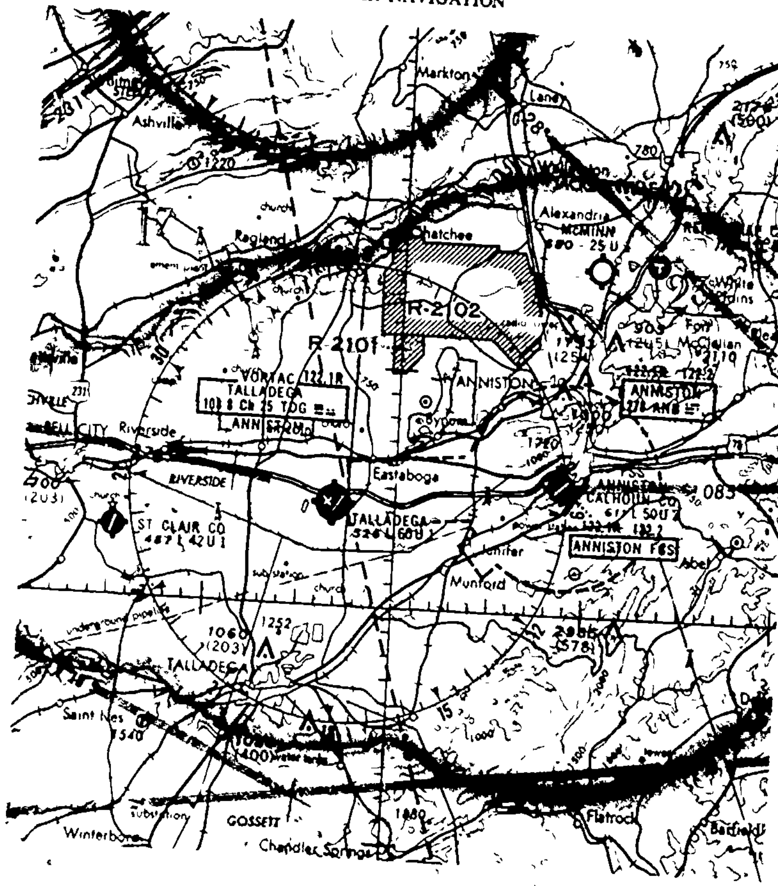


Figure 65. A VORTAC Symbol Displayed on a Chart

The ILS is a system whereby pilots can land their aircraft where the visibility is poor. The CDI and the **glide slope indicator (GSI)** receive signals from the ground and display them on the indicator, telling the pilot whether he is left or right of the runway centerline. The GSI tells him whether he is high or low or whether he has the right altitude or glide path to make good his landing touchdown point.

A series of beacons is used in conjunction with the ILS system to let the pilot know how far he is away from touchdown. The marker beacon light flashes when the aircraft passes over two specific positions on the ILS final approach to landing. The **outer marker** is located four to seven miles from the runway The **middle marker** is located approximately 3,500 feet from the runway and indicates to the pilot that, if he doesn't have the runway in sight, he must go around and try another approach. In addition to the flashing light a high-pitched squeal comes through the radio to warn the pilot when he reaches the middle marker. The ILS is the primary landing approach used by the airlines.

CELESTIAL

You are a navigator in an Air Force B–52. Your mission today is to fly undetected across the North Pole. There are no VORs, VORTACs, or any other navigation aids around the North Pole. If you turn your radar on, you can be detected. What do you do under these conditions?

You return to the primary fixing method used by the ancient mariners—**celestial navigation,** or navigation using the sun and stars. When the ground is not visible and a position cannot be established with other methods, when you are flying on long overwater flights, or when you are flying over uncharted areas, celestial navigation is an excellent aid. It has worldwide utility and is extremely useful in polar regions where nothing else is available. Furthermore, this type of navigation is not subject to enemy detection or jamming.

Celestial observations serve two purposes. First, they provide a means of fixing an aircraft's position. Second, they may serve as direction-finding references to check the accuracy of compass headings.

Celestial sightings must be taken with a special instrument, the **sextant.** Before he can identify the stars to be used for a celestial fix, the navigator must go through a **precomputation** of the position of the stars for the precise time when he will observe them with the sextant. To do this, he must use the **Air Almanac** and celestial tables for locating the position of the celestial body to be observed.

After precomputation, the navigator observes or "shoots" with his sextant one of the stars that he has selected. He shoots the altitude of the celestial body above the horizon. Using a DR position as an **assumed position,** the navigator figures the difference between the altitude of the star computed from the assumed position and the altitude observed with the sextant. This difference indicates how far away the aircraft is flying from its assumed position. From this, a celestial **line of position (LOP)** is plotted. The aircraft is known to be located somewhere along this line.

At night, the navigator observes at least two other stars through his sextant, repeating the procedures above. Three intersecting LOPs indicate the aircraft's actual position and give a fix. During the day when only the sun is available, we cannot get a fix unless we cross the sun LOP with an LOP from some other aid, such as radio or LORAN.

RADAR

The term **radar** stands for radio detection and ranging. Radar works on an echo principle. A high energy radio signal is transmitted. The signal travels until it contacts an object, and then it is reflected back to the radar antenna (Fig 66).

The radar antenna relays this signal to a **cathode ray tube (CRT)** or **radarscope** where it is displayed. The distance to the target is determined by measuring the time required for the radar signal to reach the target and return to the antenna. The radar signal travels at the speed of light and makes the round trip in **microseconds** (a microsecond is one millionth of a second).

There are now many uses for radar: catching speeders on the highway, air-to-air intercepts for air defense aircraft, ships avoiding other ships, weather stations in locating storm areas, etc.

For air navigation, there are two primary uses of radar. First, airborne radar can be used to locate targets on the ground. By using DR and referring back and forth between radar and the chart, you can determine the aircraft's position. Proficiency in in-

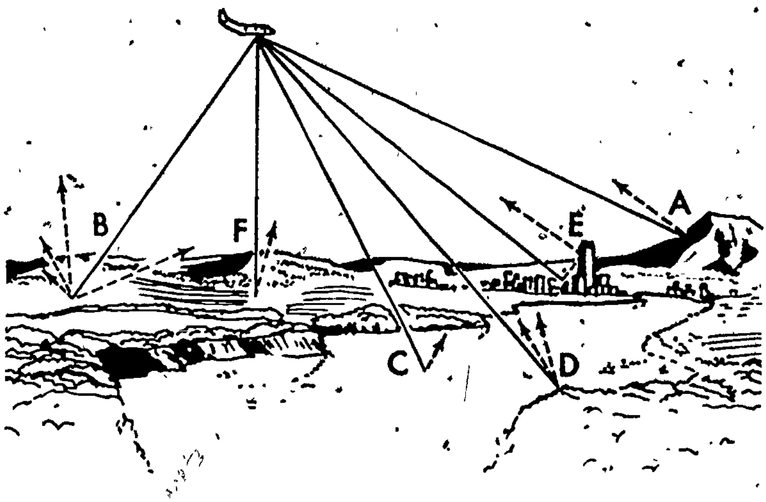


Figure 66. Radar Beams Reflect Differently from Various Types of Terrain.

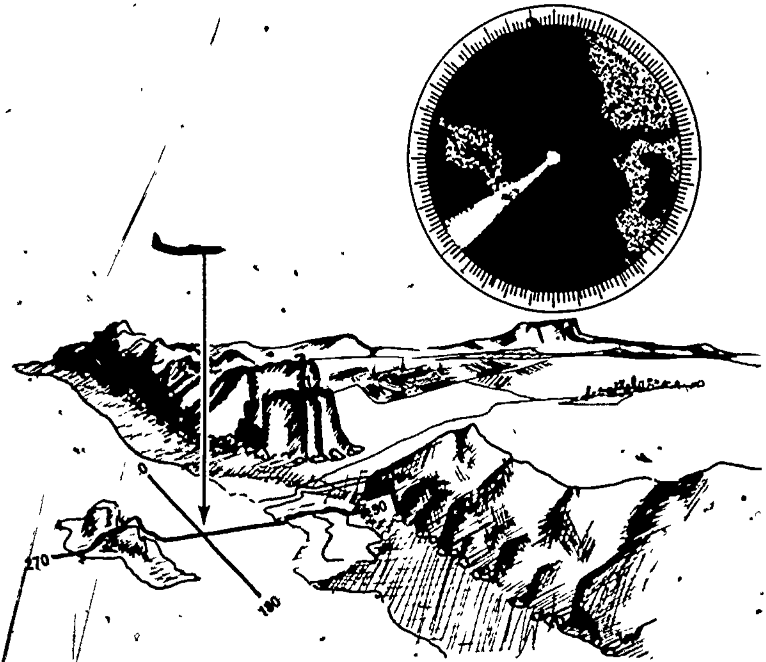


Figure 67. A typical Radar Scope Picture.

terpreting a radarscope requires a great deal of practice. Figure 67 shows a typical radarscope picture.

The second navigational use of radar is made in air traffic control. A radar located on the ground can keep aircraft flying in the radar's area under surveillance and provide navigational assistance.

Radar is also used to aid pilots in making approaches to airports. The airport approach control at most major airports has **precision approach radar (PAR)** which gives very accurate range, azimuth, and glide path information. PAR can be used to guide the pilot and his aircraft to the touchdown point without the pilot seeing the runway.

LORAN

Long-range navigation (LORAN) is used mainly by aircraft flying over ocean routes. Practically all ocean areas of the Northern Hemisphere are served by LORAN stations. Aircraft must have a special LORAN receiver and special LORAN navigation charts to use this system.

LORAN stations are operated in pairs, each pair consisting of a master station and a slave station. Figure 68 shows the **master station** and the **slave station** sending out signals to the aircraft flying between them. A pilot first tunes his LORAN receiver to the desired pair of stations. The first signal received comes from the master station. After a set delay, the slave station emits its signal on the same frequency. Although the master signal is always received first, the time interval between the reception of the master signal and the reception of the slave signal varies according to the position of the aircraft. The LORAN receiver within the aircraft measures the time difference between the two signals.

This time difference is constant at any one location, but there is more than one point from which the same time difference may be measured. A line drawn through all such points takes the shape of a curved line called a **hyperbola.** LORAN navigation charts include a series of hyperbolas that represent various time differences for LORAN signals.

On his LORAN chart, the navigator locates the hyperbola for the time difference measured by his LORAN receiver. Since this curved line passes through all points for which this time difference applies, the aircraft is located somewhere along this line.

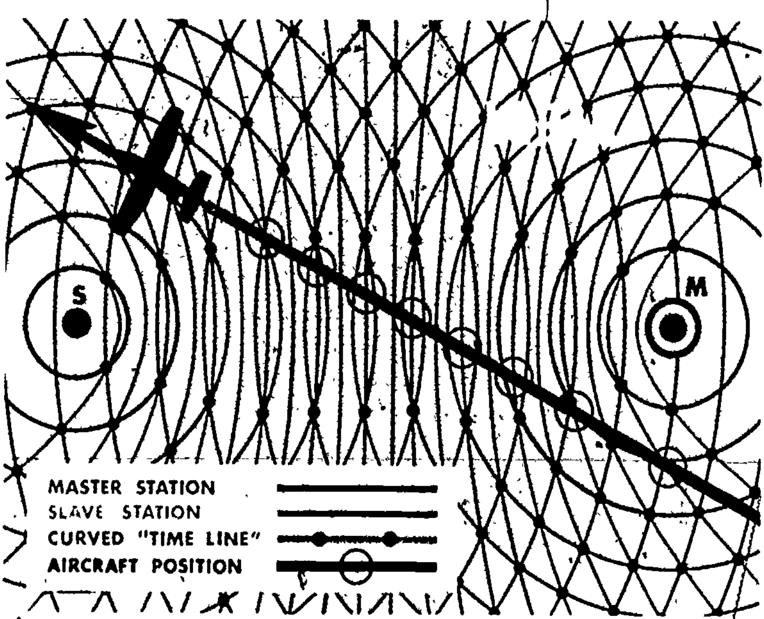


Figure 68. Long Range Navigation System (LORAN)

On the LORAN chart, the hyperbola that corresponds to this time difference is the LORAN line of position on which the aircraft is located.

A second set of LORAN signals is received, and the time difference for this set is determined by the receiver. This time difference is also plotted on a LORAN hyperbola chart, and another line of position can be established. The position of the aircraft is then determined as the point where these two lines intersect.

DOPPLER

Since man first flew, he has searched for a way to determine groundspeed and drift angle without aid from the ground. The ideal system would solve the navigation problem any place in the world and would not be susceptible to jamming, dependent on ground transmissions, nor capable of use by the enemy for a counterattack. The system would also need to be flexible enough to track aircraft even though they make unplanned deviations from the preflight course. Unlike celestial navigation, which can be rendered useless in bad weather or flights below clouds, an ideal system must also be capable of operating at any altitude or in any weather. Such an ideal system is being approached by the Doppler effect and inertial navigation.

Doppler is named after Christian Johan Doppler, a German mathematician who discovered the principle of **Doppler effect.** Doppler effect can be observed by listening to the whistle of a passing train. As the train approaches, its whistle, as heard by a stationary observer, has a fairly steady pitch which is higher than the true pitch. The speed of the approach is being added to the speed of sound. As the train passes, the ptich drops quickly to a frequency below the true pitch and remains at the lower frequency as the train moves away from the observer (Fig 69). Now the travel speed is being subtracted from the speed of sound.

By using this principle of frequency shift and a computer, we can measure the movement of an aircraft over the ground. The Doppler set transmits four radar beams downward at such angles that they outline the corners of a large rectangle beneath the aircraft The Doppler effect shifts the frequency of the radar signals reflected back to the aircraft in proportion to the movement of the airplane The frequencies of the reflected signals are compared with the frequency of original signals, and the difference is measured by the Doppler set The data that is obtained from each of the four beams is then fed into a computer, and the computer calculates the drift angle of the aircraft and its exact groundspeed

The Doppler system constantly adjusts to changes in wind direction, aircraft attitude, and engine power, and it gives instantaneous indications of each. Presented to the pilot/navigator is such information as constant present position, miles-to-go to destination, and the extent to which the aircraft is off course. The computer may also be connected to the automatic pilot in many aircraft to keep the aircraft on course automatically.

INERTIAL NAVIGATION SYSTEM

The speed of present-day supersonic aircraft and missiles requires more sophisticated navigational systems than those of the past. The problem has been solved by the development of a reliable, accurate **inertial navigation system (INS).** Inertial navigation uses measurement of acceleration and is based on Newton's laws of motion. Although the basic concept of inertial navigation has been known for years, development was delayed because the required precision parts could not be manufactured.

The INS is small and versatile, and it can be designed for missiles, fighters, or bombers. It is a self-contained unit requiring no

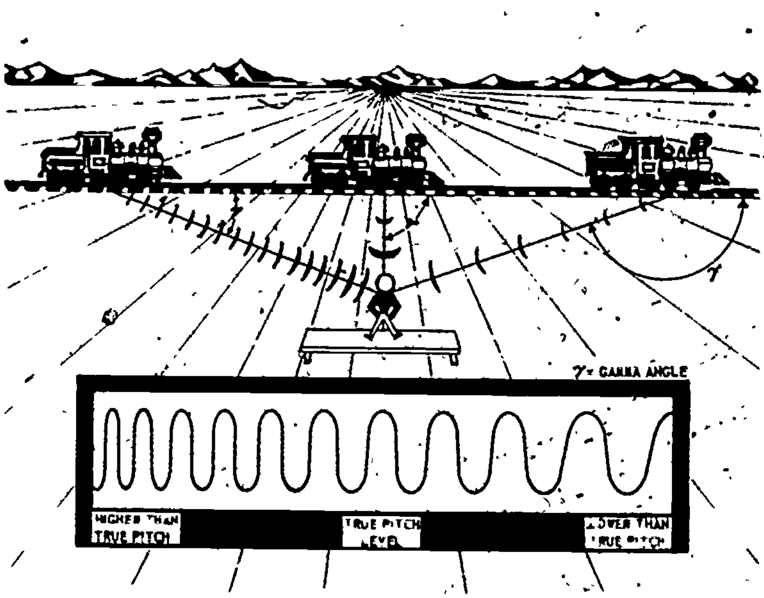


Figure 69. Doppler Effect.

external inputs other than operating power. For this reason, it cannot be affected by electronic countermeasures.

To use the inertial navigation system, an accurate fix is found through pilotage, celestial, or other means. When this accurate fix or position has been set into the system, the inertial unit maintains a correct read-out of the aircraft position during flight. The distance and direction flown is computed from information provided by a device called an **accelerometer.**

The accelerometer is set into a **stable platform,** which is the heart of the INS. With this gyro-stabilized platform, the INS is not affected by aircraft maneuvers. The stable platform allows the INS to use only those movements affecting navigation.

All information on aircraft movement is fed into a computer that converts the information into present position coordinates, groundspeed, distance, and heading from last fix, distance, and heading to destination, and wind components. In other words, when the INS is working properly, it solves the DR problem for you.

INS is now used not only by airplanes, ships, and submarines but also by ICBMs and space rockets for navigation.

WORDS AND PHRASES TO REMEMBER

fix
ADF
homing
Bird Dog
VOR
MHz
omni
course deviation indicator (CDI)
course selector
radio facilities chart
TO-FROM indicator
DME
transponder
interrogator
slant range
TACAN
VORTAC
ILS
GSI
outer marker
middle marker
celestial navigation
sextant
precomputation
Air Almanac
assumed position
LOP
radar
CRT
radarscope
microseconds
PAR
LORAN
master station
slave station
hyperbola
Doppler effect
INS
accelerometer
stable platform

QUESTIONS

1. Why do we need navigation aids other than DR and pilotage?

2. A new point of departure or a point that cancels previous DR errors is called a ____________________.

3. When you have a crosswind and you are homing on an ADF, you will fly a (straight/curved) course.

4. VOR operates between frequencies __________ MHz and __________ MHz.

5. A VOR radial is a _______________ direction (to/from) the station.

6. TACAN gives the same information as a VOR plus:
   a. Magnetic bearings
   b. Distance to the station
   c. Distance from the station
   d. b and c above

7. Explain how to plot a magnetic course from a VORTAC.

8. Name three things found in the identifying data of a VORTAC.

9. Name the three basic parts of the VOR indicator.

10. You have set 270 on your course selector and FROM is showing on the TO-FROM indicator. What course must you fly to get to the station?

11. When the TO-FROM indicator flips from TO to FROM you are:
    a. passing over the station
    b. on the 090° radial
    c. in a turn
    d. on the 270° radial

12. When are the CDI and GSI used together?

13. What action should the pilot take if he does not see the runway by the middle marker?

14. What are the two cockpit indicators that the airplane is over the middle marker?

15. What are the advantages of celestial navigation?

16. What are the two primary uses of celestial sightings?

17. The instruments and or books used in celestial navigation are:
    a. Air Almanac, LOPs, celestial tables
    b. sextant, assumed position, celestial tables
    c. Air Almanac, celestial tables, LOPs
    d. Air Almanac, sextant, celestial tables

18. How is distance measured on radar?

19. The radar signal travels at the ______________________________ ________________.

20. What are the two navigation uses of radar?

21. True or False. The advantage of LORAN is that it takes no special equipment.

22. Doppler uses ____________ beams to measure the aircraft's movement of the aircraft.
   a. one
   b. two
   c. three
   d. four

23. INS is based on ________________________ laws of motion.

THINGS TO DO

1. Ask an Air Force navigator to come to class and explain the practical aspects of each of the navigation aids. Find out what are best for wartime conditions and which work best in airline type flying.

2. There are many types of hand-held sextants. Some are used for ships, and there are others still in existence which were used by the Air Force. Obtain one along with the Air Almanac and celestial tables. Review AFM 51–40. which your unit has, and try to take some star shots. If you can't find a sextant, try some precomputations using the books.

3. Go back to Chapter 2. Replan that mission using ADF, VOR, and VORTAC. Attempt to fly with an instrument pilot and have him show you the use of ADF, VORTAC, and ILS.

SUGGESTIONS FOR FURTHER READINGS

US Air Force AFM 51–37, *Instrument Flying*, Washington, DC, Department of the Air Force, 1971.

US Air Force AFM 51–40, *Air Navigation*, Vol 1, Washington, DC, Department of the Air Force, 1968.

Bridges, Kenneth D., *Bridges Aviation Studies*, Seattle, Washington: Bridges Aviation Studies, August 1972.

Kershner, William K., *The Instrument Flight Manual*, Second Edition, Ames, Iowa: Iowa State University Press, 1792.

Lyon, Thorurn C., *Practical Air Navigation*, Denver, Colorado· Jeppeson, 1972.

Sanderson, *Aviation Fundamentals*, Denver, Colorado· Sanderson, 1972.

Appendix A

THE PLOTTER

NOTE. A plotter and a navigation chart are helpful training aids for learning material in this section.

THE PLOTTER is a small transparent instrument designed to draw and measure lines in desired directions on navigation charts. The plotter is made of transparent plastic, therefore, you may read through the plotter as you work. Since it is plastic, special care should be taken to prevent breaking it or leaving it in a hot area, such as an aircraft instrument panel where the heat can melt or warp it.

The plotter has two basic components (Fig 70). It consists of a semicircular protractor with a straight edge attached to it. Direction is measured with the protractor, and the straight edge is used in drawing lines.

Two complete direction scales located on the outer edge of the protractor are graduated in degrees. Inside these two scales are two other scales labeled 150 to 210 and 330 to 030. The direction scales are labeled every 10°. Each smaller increment equals one degree. The outer protractor is used for measuring direction between 000° (360°) and 180°. The inner scale of the protractor is used for measuring between 180° and 360°.

Both the outer and inner scales increase in a counterclockwise direction. In Figure 71, the arrow points to __________° on the scale. (Do not write answers in book).

The difference in the readings on the inner and outer scales is 180°. For instance, 080° on the outer scale is next to 260° on the inner scale. This difference of 180° exists for every point on the two scales. In Figure 72, the reading at arrow A is ______, and the reading at arrow B is ______.

On a Lambert chart, the meridians converge toward the poles. For this reason, a rhumb line and a great circle course have approximately the same direction at the mid-meridian of the proposed flight path. Since it is easier to fly one heading along a planned route, the course direction should be measured at the mid-meridian (mid-longitude).

The first step in measuring the course and distance to be flown is to plot the departure and destination points on the chart. Draw

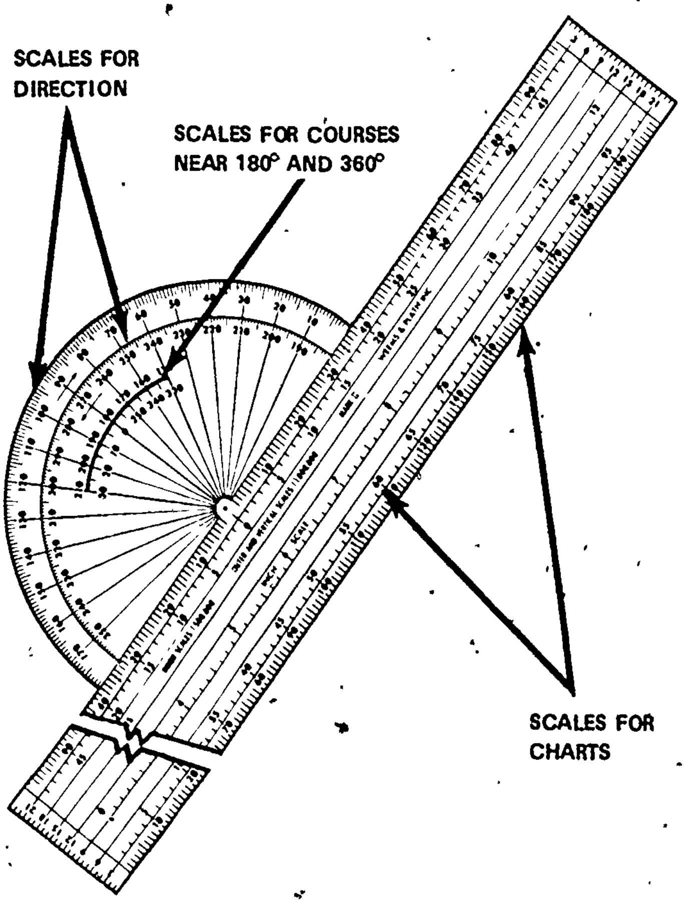


Figure 70 Plotter.

the course line between these two points. If they are close together, the straight edge of the plotter can be used. If they are far apart, two plotters or a plotter and some other straight edge can be used together.

After the course line has been plotted, the next step is to determine its direction. Place the plotter on the course line so that the small hole in the center is located over the mid-meridian (Fig 73).

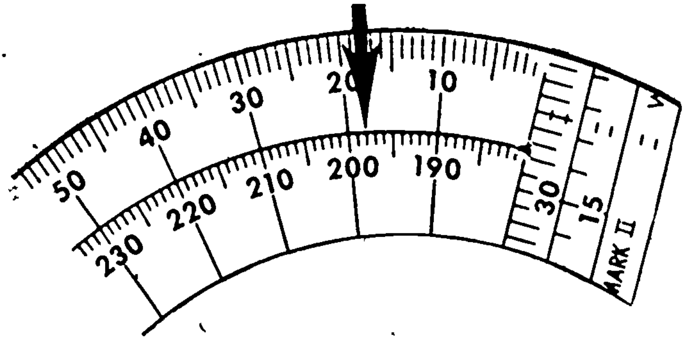


Figure 71. 198° Inner.

The course direction is the angle between the vertical line on a meridian and the course line. This angle is measured by placing the meridian under the hole and aligning the base of the plotter parallel to the course line.

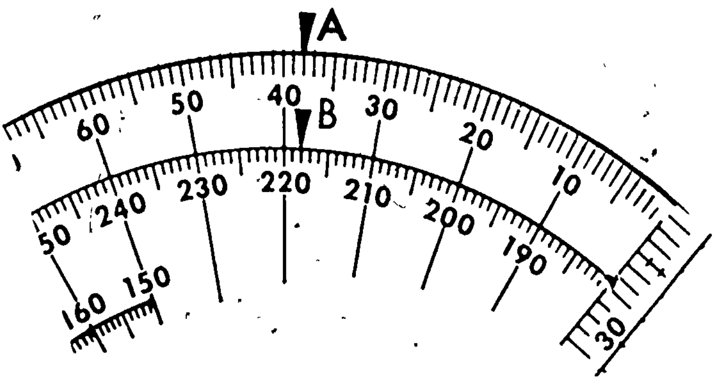


Figure 72 A = 038° B = 218°

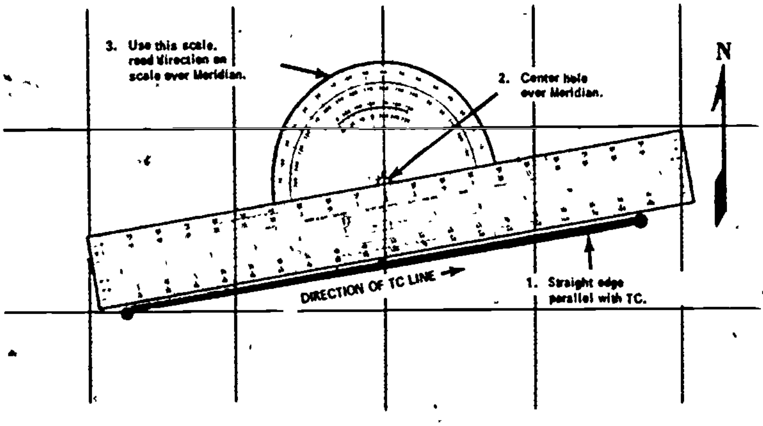


Figure 73. To Measure True Course.

A course line has two possible directions. the correct one and the opposite or reciprocal. For example, if you go due east, your direction is 090°. If a line is drawn from where you are toward the east, it has a direction of 090°, but the line also could be measured the reciprocal of 090°, which is 270° or due west. The error of plotting and measuring reciprocals is, unfortunately, all too common, and such mistakes have resulted in serious trouble for many pilots and navigators.

Just as the course line has two possible directions, so does the protractor on the plotter. Small arrows are found on most plotters near the 90°-270° marks to minimize the possibility of reading the wrong scale. The best method to avoid measuring reciprocals is to remember that, for courses plotted in an easterly direction, you must read the inner scale.

If the meridian is not long enough to measure the direction, manipulate the plotter so that one of the distance scales is superimposed on the course line with the center hole still on the mid-meridian (Fig 74).

For a line that runs nearly north or south, it is difficult to align the hole in the plotter with a meridian. In this case, the easiest solution is to use a parallel of latitude as a reference instead of a meridian. To do this, you use the auxiliary scales located under the regular direction scales on your plotter. The auxiliary scales have a 60° range. which is divided 30° on each side of 000° or 180°.

Like the regular measuring scales, the auxiliary scales increase counterclockwise. The outer auxiliary scale starts at 150° and increases to 210°. The inner auxiliary scale starts at 330° and runs through 000° to 030°. If you want to measure the direction of a course line located near 180°, or south, you use the outer auxiliary scale, when measuring a course line near 000°, or north, you use the inner auxiliary scale. When measuring directions near 180° or 000°, slide the plotter until the center hole of the protractor is located over a parallel of latitude. Read the direction on the appropriate auxiliary scale as shown in Figure 75.

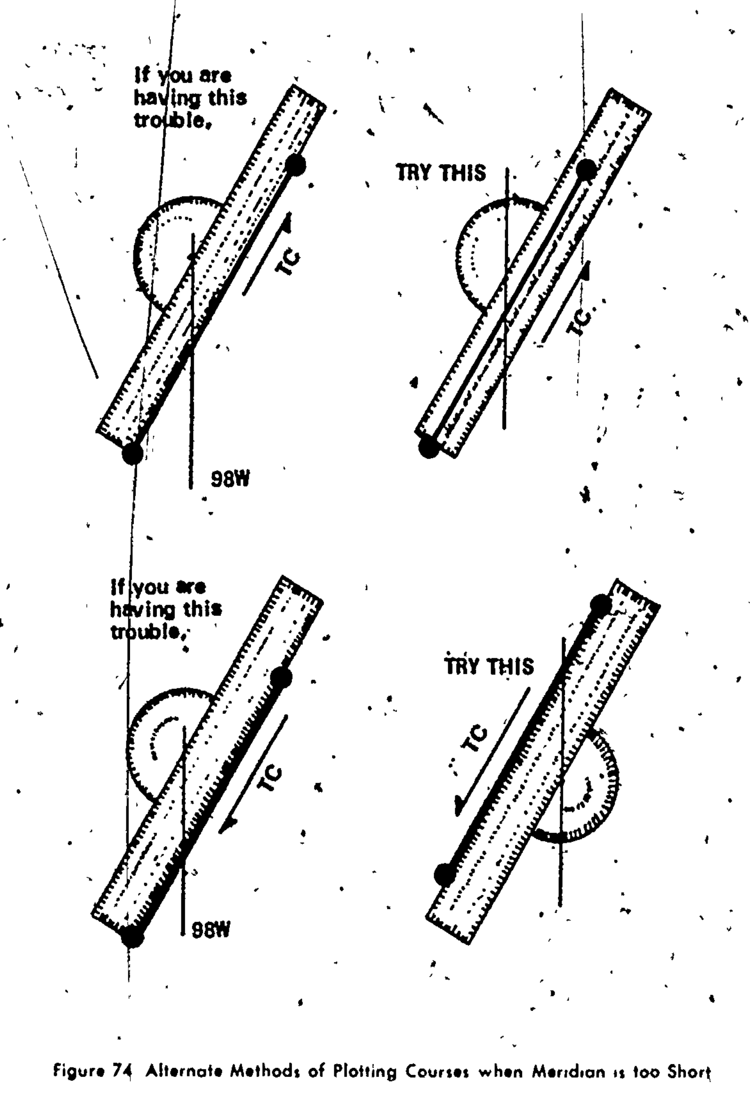


Figure 74 Alternate Methods of Plotting Courses when Meridian is too Short

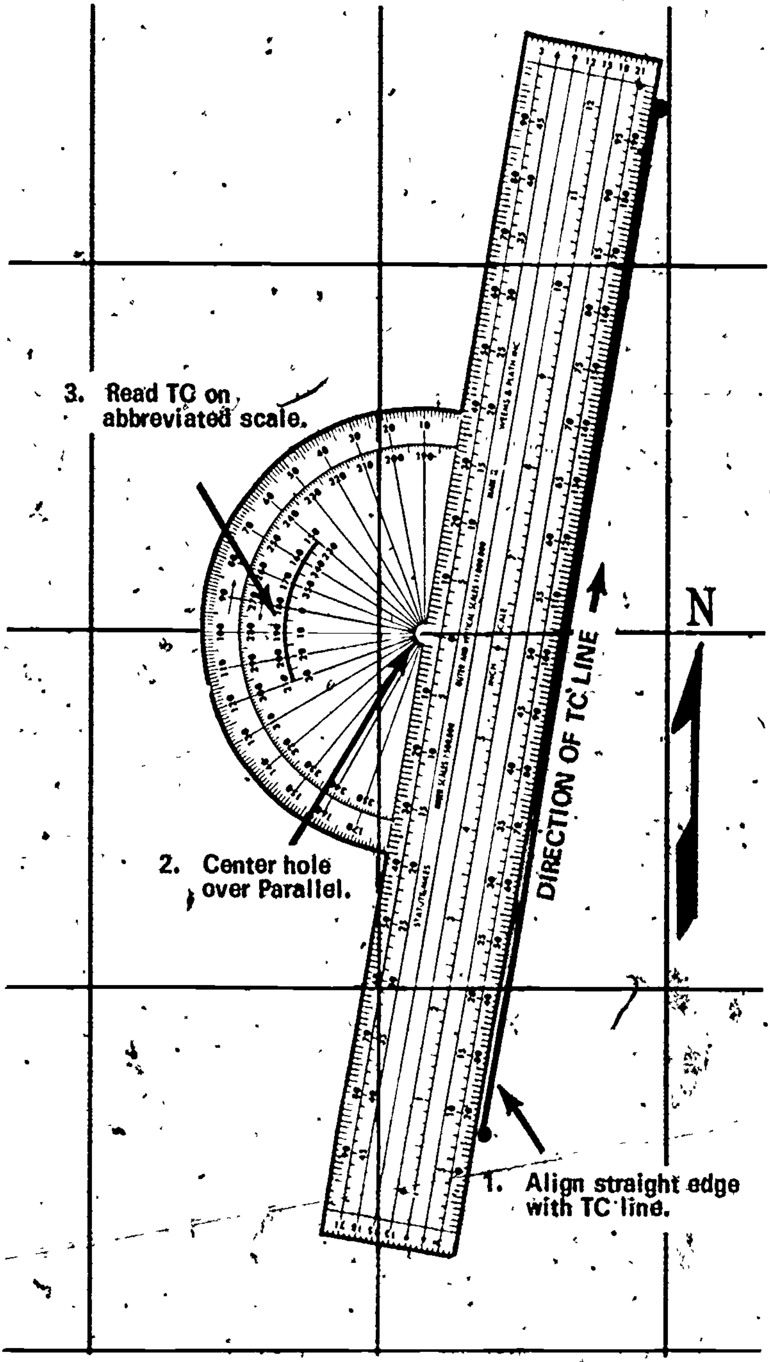


Figure 75. To Measure True Course Near 180° or 360°.

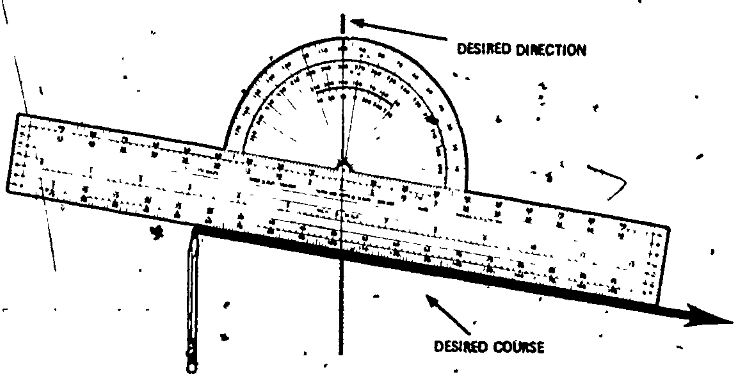


Figure 76. To Draw a Course Line.

To draw a course line in a given direction from a known point, place your pencil point and straight edge on a known point. Then slide and pivot the plotter around the pencil point until the center hole and desired direction are aligned along the same meridian. After you have aligned your plotter, draw the course line along the straight edge with your pencil (Fig 76).

Most plotters also have scales for measuring distances. These scales vary according to the type of plotter. Some use statute miles, others nautical miles. Some have distances marked off for charts with 1.500,000 scales. Some have distances for charts with 1.1,000,000 scales, other plotters have scales for both. Before using the plotter to measure distances, be sure that you are using the correct scale.

On the Lambert Conformal Chart, one minute of latitude equals one nautical mile. Any part of a meridian graduated in minutes of latitude can be used to measure distance. Measure the length of the course line on the chart, lay it next to the graduated meridian, and count the number of minutes of latitude. This number equals the total nautical miles.

Every chart has a scale of both nautical and statute miles. This scale can also be used to measure the distance of the course line.

Appendix B

THE DEAD RECKONING COMPUTER

NOTE. To attain maximum benefit from this section, you should use a dead reckoning computer.

THERE ARE two components of the navigation computer, and these are placed back-to-back. One side is a circular slide rule that can be used for arithmetic problems and is used in flying to figure time, distance, and other problems. On the other side, the vectors of the wind triangle can be displayed.

SLIDE RULE FACE

The slide rule (Fig 77) consists of two circular scales, one a stationary scale (the Miles Scale), the other a rotating scale (the

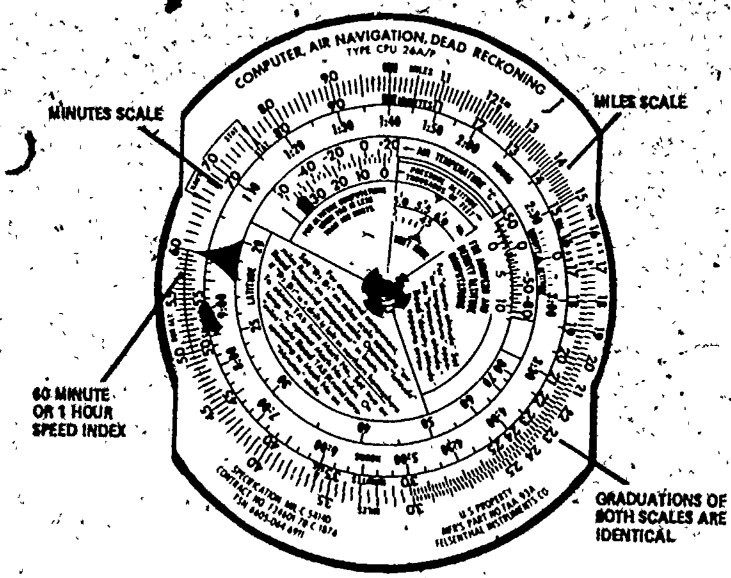


Figure 77. Slide Rule Face of the Dead Reckoning Computer.

Minutes Scale). Each scale has a reference mark, the 10 called the "Index". The rotating scale also has a black arrowhead at the sixty-minute or one-hour point, which is known as the "Speed Index". Graduations of both scales are identical. The graduations are numbered from 10 to 100, and the unit intervals decrease in size as the numbers increase in size. Not all unit intervals are numbered, and the first element of skill in using the computer is the ability to read the numbers.

Unit intervals that are numbered present no difficulty. The primary problem lies in determining the correct values for the many small lines located between numbered intervals. There are no numbers, for example, between 25 and 30, but it should be obvious that the larger intermediate divisions are 26, 27, 28, and 29. Between 25 and (unnumbered) 26 there are five smaller divisions, each of which is .2 of the larger unit. If you go back to the numbered units 10 and 11, you will find that the interval between the two numbers is divided into 10 smaller divisions. Each of these would be .1 of the larger unit, and the longer mark at the center would indicate the .5 value. Practice in reading the numbers will give you the required skill.

To find a number, such as 278, first find the 27 (for 270); then find the 28 (for 280), and then locate the fourth intermediate division (for 278). Each division has two units. For a number, such as 27812, the point already chosen for 278 would be used. This same point would also be used for 27.8, 2.78, etc. Placing the decimal point is done largely by using common sense.

The slide rule face of the dead reckoning computer is so constructed that any relationship between two numbers, one on the stationary scale and one on the movable scale, will hold true for all other numbers on the two scales. If the two 10s are placed opposite each other, all other numbers will be identical around the whole circle. If 20 on the inner scale is placed opposite 10 on the outer scale, all numbers on the inner scale will be double those on the outer scale. If 12 on the outer scale is placed oppoiste 16 on the inner scale, all numbers will have a three-to-four relationship. This feature of the slide rule permits you to supply the fourth number of any mathematical proportion. The simplest and most useful application of this feature of the computer is the solution of time, speed, and distance problems.

Time Speed, and Distance. A plane has traveled 24 nautical miles miles (nm) in 8 minutes. How many minutes will be required to travel 150 nm? The answer is the missing number in a simple proportion:

$$\frac{24}{8} = \frac{150}{?}$$

In this form, the proportion may be set on the computer exactly as it appears, with 24 on the outer Miles Scale opposite 8 on the inner Minutes Scale. You now can read the number opposite 150 nm and find it to be 50 minutes. You can also read the rate of speed opposite the arrowhead "speed index". In this case, the rate is 180 nautical miles per hour or 180 knots. In addition to the Minutes Scale, an inner Hours Scale is used for reading times in excess of one hour. For instance, under 24 on the inner scale is 4:00 or 4 hours.

Using this basic proportion principle, you can solve many types of flying and math problems.

Math Problems. The key to solving math problems on the computer is the unit index, which is the 10 (or 1.00, 100, 1000). The unit index is marked by a black box on both the rotating inner and fixed outer scales.

To multiply, rotate the inner scale until the unit index is opposite one of the numbers on the outer scale. Opposite the other number on the inner scale, read the answer (product) on the outer scale. For example, if we wanted to multiply 36 times 15, we would place the unit index under 36 on the outer scale. Read the answer (540) on the outer scale opposite the 15 on the inner scale. Work the following problems and check your products against the answer sheet at the end of the Appendix. Do not write your answers in the book. Multiply a by b.

	a	b	Product
1.	210	10	....
2.	375	12	....
3.	26	26	....
4.	52.5	90	....
5.	106	10.5	....
6.	215	110	....
7.	19.6	12	....
8.	.084	41	....
9.	.32	4.2	....
10.	2.1	156	....

To divide, the multiplication process is reversed. The dividend (number to be divided) is placed above the divisor on the inner scale. The answer is read on the outer scale opposite the unit index. For example, if we wanted to divide 2700 by 25, we would place 25 under 27 (2700) and read the answer (108) on the outer scale over the unit index. Work the following problems and check your quotients against the answer sheet at the end of the Appendix. Do not write your answers in the book. Divide a by b.

	a	b	Quotient
1.	241	10	....
2.	170	15	....
3.	27.8	8	....
4.	525	25	....
5.	4380	219	....
6.	1550	310	....
7.	57	14.8	....
8.	341	98	....
9.	100	24.3	....
10.	220	19	....

Time, Speed, and Distance. Suppose you are flying in a light airplane, and you have traveled 36 nautical miles in 12 minutes, how fast are you going? This is one typical problem that can be solved with your computer. This problem and many others can be solved in a few seconds using one hand. Therefore, you can work problems and fly the airplane at the same time.

In the problem above, you set the 36 on the Miles Scale over the 12 on the Minutes Scale and read your ground speed opposite the black arrowed speed index. In this example, you are flying 180 knots.

Using this same example, suppose that you have 210 nm to go. How long will it take you, assuming that you will fly the same groundspeed? Leave the speed index under 180, read the time that it will take you to travel the 210 nm opposite 21 on the miles index. The answer is 70 minutes or 1 hour and 10 minutes.

Another problem common to almost all flights is determining the distance traveled at a given speed after a given amount of time. For example, how far would you go in 36 minutes at 167 knots? Set 167 (one-half the distance between 166 and 168) over the speed index and read the distance over 36 on the Minutes Scale. You find that you would travel 100 nm. Find the missing quantities, check your answers against the answer sheet in the Appendix. Do not write your answers in the text.

	Time	Speed	Distance
1.	....	145k	128nm
2.	1:17	150k	......nm
3.	....	164k	197nm
4.	:33	......k	78nm
5.	:36	139k	......nm
6.	:18	......k	47nm

	Time	Speed	Distance
7.	....	132k	203nm
8.	1:18	......k	194nm
9.	:47	147k	......nm
10.	1:34	......k	412nm

Fuel Consumption. Another important use of the computer is the solution of problems concerned with fuel consumption. It gets lonely and mighty quiet when you run out of fuel at 3,000 feet, 20 miles short of your destination.

Problems in fuel consumption are solved in the same manner as speed problems, except that the rate is expressed as gallons per hour (gph) instead of miles per hour. Therefore, gallons, like miles, are read on the outer scale. The arrow is again used as the rate index.

You are one hour from your destination, and you are burning 85 gallons per hour (gph) with 150 gallons remaining. Do you have enough fuel to make it? The first step is set the speed index (black arrow) to the rate of consumption (85 gph). Under the fuel available (150 gallons) on the Miles Scale, read the time of flight on the hours scale (1.46). In our problem, we have 1 hour and 46 minutes of fuel with one hour to fly. We would reach our destination with 46 minutes of fuel in reserve.

In another case, assume that you have flown 1 hour and 28 minutes and have burned 135 gallons of fuel. What is your rate of fuel consumption? Under the total fuel consumed (135 gas), set the time (1:28) on the inner scale. Read the rate of consumption (92 gph) on the outer scale opposite the arrow.

Another important aspect of preflight planning is calculating the total fuel required for the flight. Let's assume that you are figuring a flight that will last 2 hours and 10 minutes, and your aircraft burns 85 gph. How much fuel is required for your flight? Set the arrow at the rate of consumption (85 gph) on the outer scale. Over the time (2:10) on the inner hour scale, read the total fuel required on the outer scale (184.5 gals). Find the missing quantities; check your answers against the answer sheet at the end of the Appendix. Do not write your answers in the book.

	Time	Rate (gph)	Fuel (gals)
1.	:35	....	17
2.	......	40	113
3.	....	23	73
4.	1:10	...	35

	Time	Rate (ghp)	Fuel (gals)
5.	....	55	238
6.	2:16	....	77
7.	2:17	43	......
8.	1:56	31	......
9.	:48	....	28
10.	3:24	15	......

Statute Miles, Nautical Miles, and Kilometers Conversion. Most navigational calculations use nautical miles and knots. In light plane flying, work is sometimes done in statute miles and miles per hour (mph). There is a move in this country to convert to kilometers in the metric system. The slide rule face of the dead reckoning computer provides a way for converting distance measures from one system into the other. This can be done by using the NAUT, STAT, and Km markings on the outer scale. To convert 220 nm to statute miles or kilometers, place 220 under the NAUT arrow and read the statute mile conversion under STAT (254) and the kilometer conversion under Km (406). Read the answers on the inner scale. Conversions of any of the other units are made in the same way. The known number is placed under the arrow for the unit in which that figure was expressed, and the unknown quantity is read under the appropriate arrow. Find the missing quantities; check your answers against the answer sheet at the end of the Appendix. Please do not write your answers in the book.

	Nautical Miles	Statute Miles	Kilometers
1.	160	....	....
2.	....	240	....
3.	....	....	35
4.	....	15	....
5.	8.5	....	....
6.	....	24	....
7.	....	....	47
8.	....	85	....
9.	92	....	....
10.	....	60	....

As you progress to more complicated instrument navigation and flying, you will learn other uses of the computer. Pilots often find it necessary to know how long it will take them to fly a very short distance, and they will usually want to know the time in seconds. The SEC (seconds) index on the DR computer gives a quick conversion. A small arrow has been placed on the Minutes or Inner scale at 36. This represents 3600 seconds or the equivalent of one hour. When this index is placed opposite a known groundspeed, the time to fly a given distance may then be read on the Minutes Scale under the distance to fly. The time will be shown in seconds.

The airspeed indicator is constructed to operate accurately under standard atmospheric conditions, (a pressure of 29.92 inches of mercury and a temperature of 15°C). In flight, these exact conditions will rarely be found. Therefore, the pilot will need to correct the readings of his airspeed indicator for pressure and temperature variations to find his true airspeed. The slide rule face of the dead reckoning computer has a special scale that will enable him to make the necessary corrections, it is labeled FOR AIRSPEED AND DENSITY ALTITUDE COMPUTATIONS.

We will not discuss the mechanics of calculating this correction here, but this should be learned before taking the FAA Private Pilot's Exam. The method is explained in AFM 51-40.

You can find altimeter corrections using the FOR ALTITUDE computations window. Density, altitude, and drift correction to parallel course can also be found. Many of these problems are being solved with modern instruments in new aircraft. Before flying, you should determine the corrections that you need and review the procedures for computing them.

WIND FACE

The wind face of the computer (Fig 78) is used to plot the wind triangle. Before attempting to use this part of the computer, you should be thoroughly familiar with the wind triangle problem.

The wind face has two parts, a circular disc and a slide. The circular plotting disc contains a compass rose and a clear plastic plotting disc with a small circle in the center called the grommet. The slide has airspeeds calibrated on both sides. One side is used primarily for lower airspeeds ranging from 0 to 270 knots. The other side is used for speeds up to 800 knots. Both sides of the slide are marked off on either side of the speed lines in degrees of drift.

The wind face of the computer can be used to compute any component of the wind triangle. In your preflight planning, you measured true course on your chart, and you obtained wind at the altitude that you plan to fly from the weather station. You know the best true airspeed from previous experience and aircraft manuals. Therefore, you have the following parts of the wind triangle.

True course (TC)
Wind direction and speed (W/V)
True airspeed (TAS)

You need to find true heading (TH) that needs to be flown to make good your TC and the groundspeed (GS) to be able to figure how long it will take you to reach your destination.

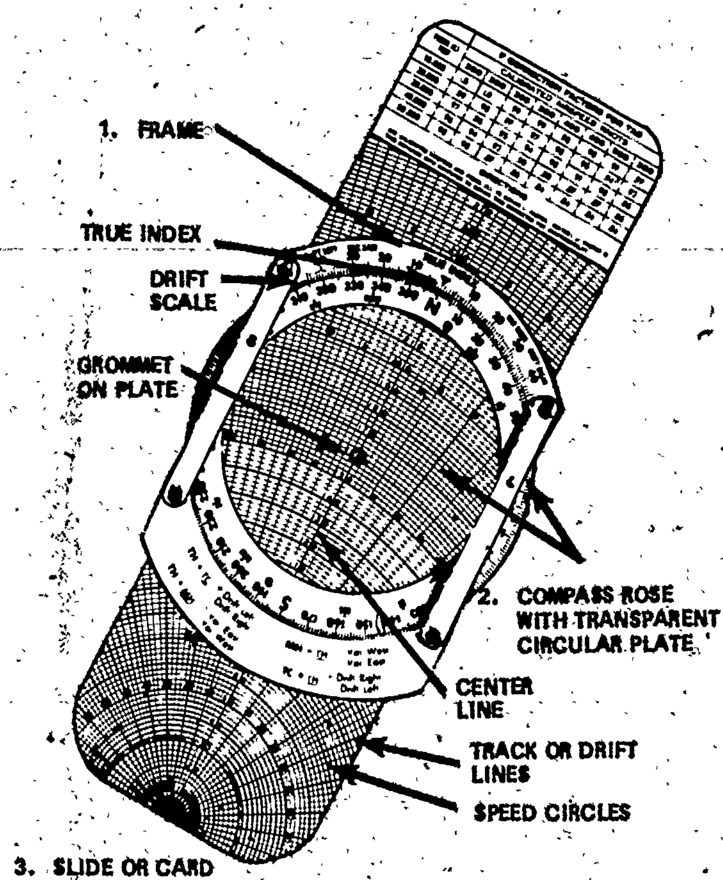


Figure 78. Wind Face of the Dead Reckoning Computer

Let's assume that you have found for your flight today the following information:

Wind Direction	- 240°
Wind Speed	- 30 Knots
True Course	- 195°
True Airspeed	- 180 Knots

You need to find on your computer:

True Heading

Ground Speed

The following is the sequence to follow in solving this probem.

a. Set wind direction (240°) under the TRUE INDEX.

b. Draw wind vector up from center of disk to the proper length for 30 knots.

c. Rotate the azimuth until the TC (195°) is directly under the TRUE INDEX.

d. Now, slide the grid through the computer until the end of the wind vector rests on the TAS (180k).

e. Note the wind correction angle (7°R). Each graduation right or left of the center line is equal to 1°. Under 150k, the graduations equal 2°.

f. Remember that a right wind correction is applied to a left drift and a left correction to a right drift. We subtract for left wind correction and add for right drift correction. We are reading drift correction angle off the computer. In our example, we have 7°R drift correction; therefore, we add 7° to our TC to attain our TH. TH in our problem equals 202°.

g. The GS can be read directly off the computer. The number underneath the grommet equals the GS. The GS in our example is 158k.

With this information, you know that, to make good your TC of 195°, you must hold a TH of 202°. You also know that your speed over the ground will be 158k. By taking this speed and setting it on the slide rule face opposite the distance to be flown, you can find how long it will take.

Exercise. Solve the following problems, check your answers against the answer sheet at the end of the Appendix.

	Wind Direction	Wind Speed	True Course	True Air-speed	True Head-ing	Ground-Speed
1.	148°	32	080°	170	....	....
2.	300°	18	010°	130	....	....
3.	015°	26	160°	190	....	....
4.	225°	15	275°	140	....	....
5.	180°	35	050°	200	....	....
6.	078°	30	190°	175	....	....
7.	110°	38	028°	300	....	....
8.	045°	25	292°	165	....	....
9.	060°	35	130°	180	....	....
10.	310°	36	206°	145	....	....

You may use the wind face side of the computer to solve other unknown components of the wind triangle. For example, you may find TC and GS or TH and TAS with the wind face if you have the other data. Wind direction and wind speed can also be found.

ANSWERS TO EXERCISE PROBLEMS

MATH PROBLEMS

PRODUCTS . . . page 119

1. 2100
2. 4500
3. 676
4. 4725
5. 1113
6. 2365
7. 235.2
8. 3.444
9. 1.344
10. 327.6

TIME, SPEED, AND DISTANCE, pages 120–21

1. :54
2. 192nm
3. 1:12
4. 142k
5. 82nm
6. 156k
7. 1:32½
8. 149k
9. 115nm
10. 262k

QUOTENT page 120

1. 24.1
2. ~~11~~:33
3. 3.475
4. 21
5. 20
6. 5
7. 38.5
8. 3.48
9. 4.12
10. 11.58

FUEL CONSUMPTION, page 121–22

1. 29.2gph
2. 2:50
3. :19
4. 30gph
5. :26
6. 34gph
7. 98
8. 60
9. 35gph
10. 51

APPENDIX B

STATUTE MILES, NAUTICAL MILES, AND KILOMETERS, page 122

	Nautical	Statute	Kilometers
1.	160	182	296
2.	208	240	335
3.	18.85	21.8	35
4.	13	15	24.1
5.	8.5	9.8	15.63
6.	20.8	24	38.5
7.	25.45	29.25	47
8.	74	85	136
9.	92	106	170
10.	52	60	96

WIND FACE, page 126

	TH	GS
1.	090½	155
2.	002	123
3.	156	211
4.	220	130
5.	058	221
6.	181	185
7.	036	293
8.	300½	172
9.	119½	165
10.	221	148

INDEX

R

S

T

U

V

W

X

Y

Z

ernment Printing Office: 1974—744-453