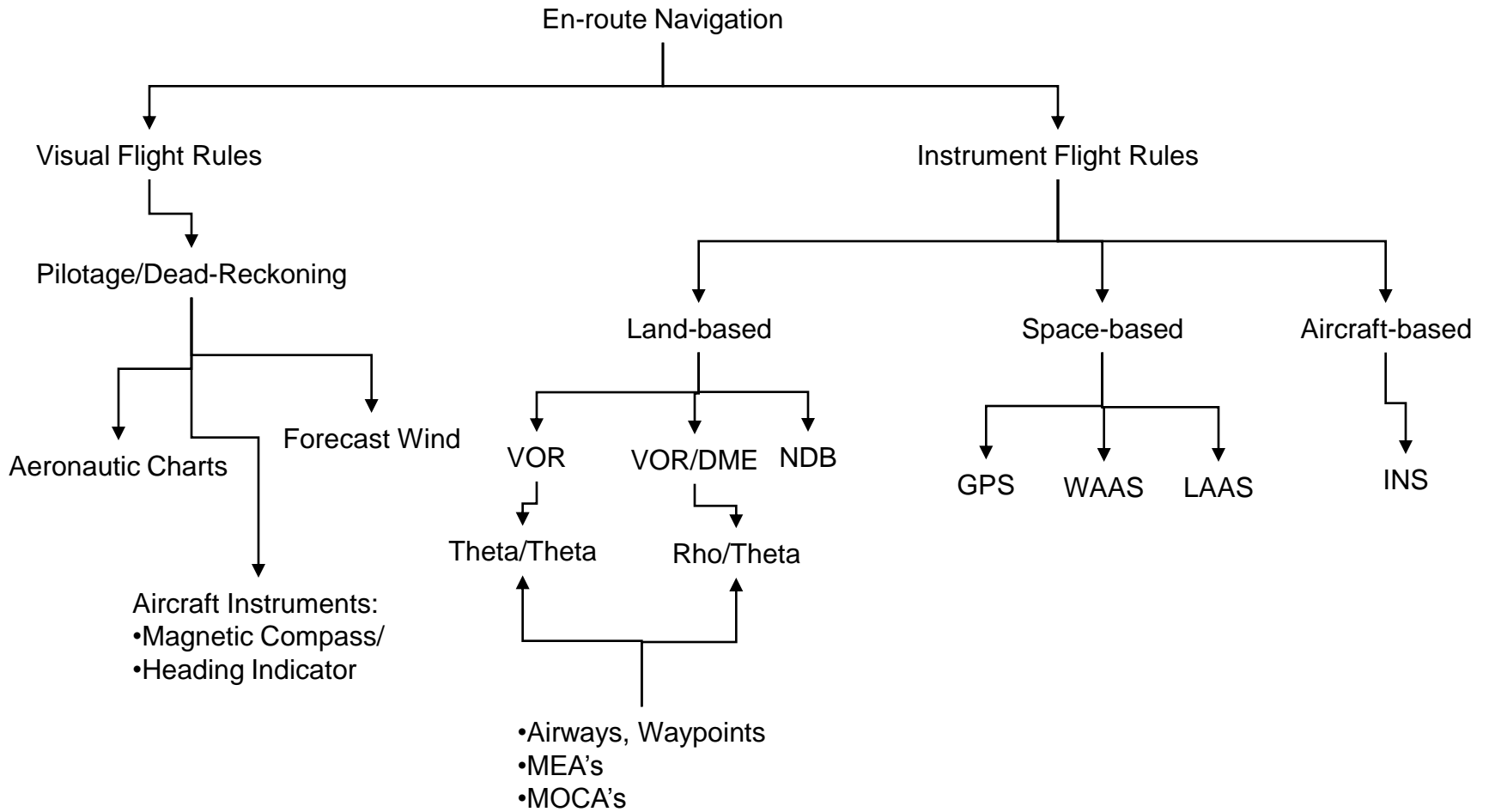


# Navigation Systems - Enroute

Nolan, Chap 2



# Navigation

- Guide aircraft from origin to destination
  - Optimum route (fuel, time)
    - Wind, altitude
  - Avoid terrain, airspace restrictions
- Navigation has Three parts:
  1. Aircraft Position Fixing
    - Where am I?
  2. Flightplanning
    - Where do I want to go?
    - What route?
  3. Guidance (also called Navigation)
    - What do I do to follow route?
    - What leg of route?

# Aircraft Position Fixing

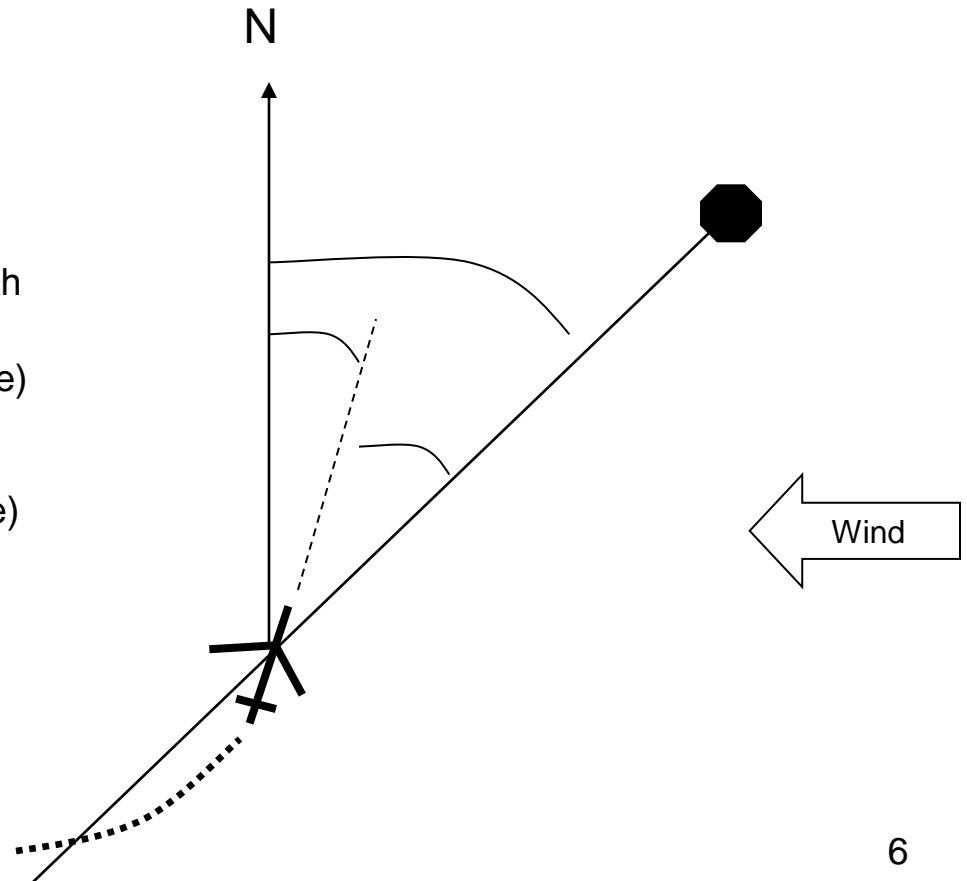
- Determine position in 4-D space
  - Latitude/Longitude
  - Altitude (ft)
  - Time (Greenwich Mean Time – GMT, Zulu Time)

# Flightplanning

- Origin
- Destination
- Lateral Route
  - String of Legs along Airways
- Vertical Route
  - Altitudes, Speeds

# Guidance (also Navigation)

- Lateral leg
  - Desired Ground Track
    - Desired “breadcrumbs” on surface of earth
  - Desired Course
    - direction over earth (True) to get to Active Fix for Lateral Leg
    - Degrees from North
  - Actual Ground Track
    - “breadcrumbs” on surface of earth
  - Actual Course
    - Direction over earth surface (True) flown by aircraft
  - Aircraft Heading
    - Direction aircraft is pointing (True)
    - Degrees from North
  - Cross-wind Correction Angle
    - Degrees between Heading and Ground Track



# Visual Navigation

- Use visual references to navigate
  - Limited to day-light flying in good conditions/weather
  - Use visual references (e.g. horizon) to control aircraft attitude for level flight
  - Use prominent landmarks to guide path
    - Adjust for crosswinds
      - Cross wind correction angle
      - Ground track course

# Visual Navigation - Pilotage

- Use map of surrounding area as a reference
- Draw line on map for route
  - Identify landmarks to use as reference
- Adjust aircraft course to fly to landmarks
- Adjust aircraft course to compensate for crosswinds
- Trial-and-Error

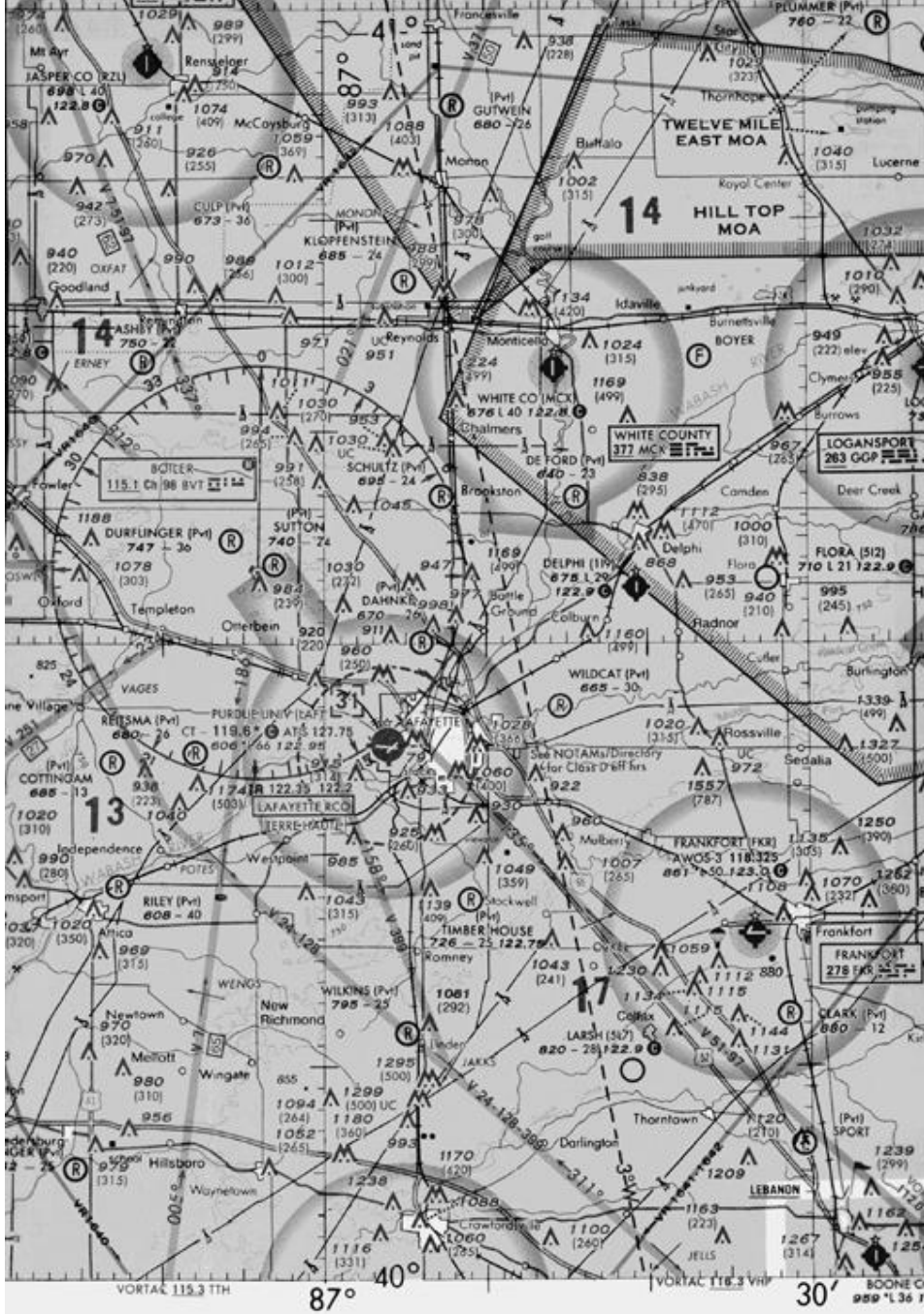


# Visual Navigation – Dead Reckoning

- Used in combination with pilotage
- Predict (not Trial-and-Error)
- Predict Desired Course
  - Compute required heading to fly desired course (and track) based on forecast winds aloft
- Forecast winds aloft not accurate

# Aeronautic Charts

- Sectional Charts



## CHICAGO LEGEND

Airports having Control Towers are shown in Blue, all others in Magenta. Consult Airport Facility Directory (AFD) for details involving airport lighting, navigation aids, and services. For additional symbol information refer to the Chart User's Guide.

### AIRPORTS

- Other than hard-surfaced runways
- Hard-surfaced runways 1500 ft. to 3000 ft. in length
- Hard-surfaced runways greater than 3000 ft. or some multiple runways less than 3000 ft.
- Open cut within hard-surfaced runway configuration indicates approximate VOR, VOR-DME, or VORTAC location.

### ADDITIONAL AIRPORT INFORMATION

- Military - Other than hard-surfaced. All military airports are identified by abbreviations AFM, NAS, AAF, etc. For complete airport information consult DOD Flight Information Publications.
- Unsettled
- Abandoned - paved having landmark value, 300 ft. or greater
- Unlighted
- Unlighted Flight Park

Services/fuel available and field landed during normal working hours depicted by use of ticks around basic airport symbol. Normal working hours are Mon-Fri 7:00 A.M. to 4:00 P.M. local time. Consult AFD for service availability at airports with hard-surfaced runways greater than 3000 ft.

★ Notifying airport beacon in operation Sunset to Sunrise.

### AIRPORT DATA

Box indicates F.A.R. 93 Special Air Traffic Rules & Airport Traffic Patterns. Airport Surveillance Radar.

NO SVFR - No Special Visual Flight Rules. FSS - Flight Service Station. NO SVFR - Fixed-wing special VFR flight is prohibited. CT - 118.3 - Control Tower (CT) - primary frequency.

★ - Star indicates operation part-time. See lower frequency tabulation for hours of operation.

★ - Indicates Common Traffic Advisory Frequencies (CTAF) ATIS 123.8 - Automatic Terminal Information Service ASOS/AWOS 135.42 - Automated Surface Weather Observing Systems. Some ASOS/AWOS facilities may not be located at airports.

UNICOM - Aeronautical advisory station VFR Advisory - VFR Advisory Service shown where ATIS not available and frequency is other than primary CT frequency.

2055 - Elevation in feet  
L - Lighting in operation Sunset to Sunrise  
72 - Length of longest runway in hundreds of feet, usable length may be less.

When facility or information is lacking, the respective character is replaced by a dash. All lighting codes refer to runway lights. Lighted runway may not be the longest or lighted full length. All times are local.

### RADIO AIDS TO NAVIGATION AND COMMUNICATION BOXES

- VHF OMNI RANGE (VOR)
- VORTAC
- VOR-DME
- Non-Directional Radiobeacon (NDB)
- NDB - DME
- Other facilities, i.e., Commercial Broadcast Stations, FSS Outlets-PCOL, etc.

**122.1R 122.8 123.6** OAKDALE (CHICAGO CHI)

**352 116.8 OAK**

**122.1R** MIAMI

Heavy line box indicates Flight Service Station (FSS). Frequencies 121.5, 123.2, 243.0, and 250.4 Canada - 121.5, 126.7, and 243.0 are normally available at all FSSs and are not shown above boxes. All other frequencies are shown. For Local Airport Advisory use FSS frequency 123.6. R - Receives only. Frequencies above this line box are removed to NAVD and site. Other frequencies at FSS providing voice communication may be available as determined by altitude and terrain. Consult Airport/Facility Directory for complete information.

### AIRPORT TRAFFIC SERVICE AND AIRSPACE INFORMATION

Only the controlled and reserved airspace effective below 18,000 ft. MSL are shown on this chart. All times are local.

- Class B Airspace
- Class C Airspace (Mode C) See F.A.R. 91.215(AAM)
- Class D Airspace
- Class E Airspace
- Class E Airspace with floor 700 ft. above surface.
- Class E Airspace with floor 1200 ft. or greater above surface that abuts Class G Airspace.
- Class E Airspace low altitude Federal Airways are indicated by center line. Intersection - Arrows are directed towards facilities which establish intersection.

2400 MSL Differentiates floors of Class E Airspace greater than 700 ft. above surface unless otherwise designated as shown above.

Class E Airspace low altitude Federal Airways are indicated by center line. Intersection - Arrows are directed towards facilities which establish intersection.

132° - V 89

Total mileage between NAD83 on direct Airways.

- Prohibited, Restricted, Warning and Alert Areas Canadian Advisory and Restricted Areas
- MGA - Military Operations Areas
- Special Airport Traffic Area (See F.A.R. Part 93 for details)

### TOPOGRAPHIC INFORMATION

- Roads
- Road Markers
- Bridges And Viaducts
- Power Transmission Lines
- Aerial Cable
- Landmark Feature - stadium, factory, school, golf course, etc.
- Outdoor Theatre
- Lookout Tower - P-17 (Site Number) 613 (Elevation Base of Tower)
- Coast Guard Station
- Race Track
- Tank - water, oil or gas
- Oil Well
- Water Well
- Mines And Quarries
- Mountain Pass
- 11823 (Elevation of Pass)

### OBSTRUCTIONS

- Group Obstruction
- Obstruction with high-intensity lights May operate part-time
- Elevation of the top above mean sea level
- Height above ground
- Under construction or reported - position and elevation unverified

NOTICE: Guy wires may extend outward from structures.

### MISCELLANEOUS

- Unlighted Activity
- Flashing Light
- Hang Glider Activity
- Maine Light
- Glider Operations
- Parachute Jumping Area (See Airport/Facility Directory)
- VPXYZ With Weapons (See Airport/Facility Directory for latitude/longitude)

# Frankfort Airport

- Class E Airspace with floor 700 ft above surface
- Hard-surface runways (2)
  - East-West runway
  - North-South runway, short
- Frankfort (FKR) Airport
  - AWOS-3 118.325 – Automated Weather Observation System, Frequency
  - 861 – Airport Elevation
  - L - Lighting in Operation Sunrise to Sunset
  - 50 - Longest runway 5000 ft
  - 123.0 – Unicom Frequency, Aeronautical Advisory Station
  - © - Common Traffic Advisory Frequency (CTAF)
- Frankfort – Navigation
  - Non-directional Beacon (NDB)
  - 278 – Frequency
  - Morse Code for checking
  - Rotating airport beacon in operation sunset to sunrise
- Miscellaneous
  - Located west of Frankfort City
  - Fuel Services 24 hours
  - Parachute jumping area – west of airport
  - Mountains North-east and South-west less than 1000ft Above Ground Level (AGL)
  - Railroad
    - North-South, south of airport
    - East-West, east of airport

# Boiler VORTAC

- Located at top of small mountain
  - 984 feet above Mean Sea Level
  - 239 feet above Ground Level
- Name –BOILER
- Frequency – 115.1
- Channel 98
- ICAO Identifier – BVT
- Morse Code Identification
- HWAS

# Airway – Victor 7

- Airway Name – Victor 7
- 65 nm between VORTAC TTH and VORTAC BVT
- Fly northbound on 5 degree Radial from TTH
- Fly southbound on 186 Radial from BVT
- WENGS Intersection using Radials from BVT and <not shown>

# In-class Exercise

- White County (MCX) Airport using chart on page 42, Chap 2, Nolan
- Describe VOR from hand-out
- Describe Airway from hand-out



## CHICAGO LEGEND

Airports having **Control Towers** are shown in **Blue**, all others in **Magenta**. Consult **Airport Facility Directory (AFD)** for details involving airport lighting, navigation aids, and services. For additional symbol information refer to the **Chart User's Guide**.

### AIRPORTS

- Other than hard-surfaced runways.
- Hard-surfaced runways 1500 ft. to 8000 ft. in length.
- Hard-surfaced runways greater than 8000 ft. or some multiple runways less than 8000 ft.
- Open cut within hard-surfaced runway configuration indicates approximate VOR, VOR-DME, or VORTAC location.

All recognizable hard-surfaced runways, including those closed, are shown for visual identification. Airports may be **active** or **prohibited**.

### ADDITIONAL AIRPORT INFORMATION

- Military - Other than hard-surfaced. All military airports are identified by abbreviations AFM, NAA, AAF, etc. For complete airport information consult DOD Flight Information Publications (FIP).
- Helipad Selected.
- Unimproved - paved having landmark value, 300 ft. or greater.
- Unlighted Flight Park Selected.

Services: fuel available and field landed during normal working hours depicted by use of ticks around basic airport symbol. (Normal working hours are Mon-Fri 11:00 A.M. to 4:00 P.M. local time.) Consult AFD for service availability at airports with hard-surfaced runways greater than 8000 ft.

**★** - Rotating airport beacon in operation Sunset to Sunrise.

### AIRPORT DATA

Box indicates F.A.R. 93 Special Air Traffic Rules & Airport Traffic Patterns. Airport Surveillance Radar.

**CT-118.3** - ATIS 123.8  
**265 L 72 122.95** - Runways with Flight Traffic Patterns (public use)  
**RP 23.34** - FSS (See Airport Facility Directory)  
**VFR Advy 125.0** - Airport of Entry

**FSS - Flight Service Station**  
**NO SVFR** - Fixed-wing special VFR flight is prohibited.  
**CT-118.3** - Control Tower (CT) - primary frequency.

**★** - Star indicates operation part-time. See tower frequencies tabulation for hours of operation.  
 Indicates Common Traffic Advisory Frequencies (CTAF)  
**ATIS 123.8** - Automatic Terminal Information Service  
**ASOS/AWOS 135.42** - Automated Surface Weather Observing Systems. Some ASOS/AWOS facilities may not be located at airports.  
**UNICOM** - Aeronautical advisory station  
**VFR Advy** - VFR Advisory Service shown where ATIS not available and frequency is other than primary CT frequency.

**265** - Elevation in feet  
**L** - Lighting in operation Sunset to Sunrise  
**72** - Length of longest runway in hundreds of feet; usable length may be less.

When facility or information is lacking, the respective character is replaced by a dash. All lighting codes refer to runway lights. Lighted runway may not be the longest or lighted full length. All times are local.

### RADIO AIDS TO NAVIGATION AND COMMUNICATION BOXES

- VHF OMNI RANGE (VOR)
- VORTAC
- VOR-DME
- Non-Directional Radiobeacon (NDB)
- NDB - DME
- Other facilities, i.e., Commercial Broadcast Stations, FSS Outlets, etc.

**122.1R 122.8 123.6**  
**352 116.8 OAK**  
**122.1R**  
**MIAMI**

FSS providing voice communication

**122.1R CHICAGO CHI**

Heavy line box indicates Flight Service Station (FSS). Frequencies 121.5, 122.2, 243.0, and 250.4 Canada - 121.5, 126.7 and 243.0 are normally available at all FSS and are not shown above boxes. All other frequencies are shown. For Local Airport Advisory use FSS frequency 123.8.

**R** - Reverses only  
Frequencies above thin line box are remoted to NAVDAD site. Other frequencies at FSS providing voice communication may be available as determined by altitude and terrain. Consult Airport Facility Directory for complete information.

### AIRPORT TRAFFIC SERVICE AND AIRSPACE INFORMATION

Only the controlled and reserved airspace effective below 18,000 ft. MSL are shown on this chart. All times are local.

- Class B Airspace
- Class C Airspace (Mode C) See F.A.R. 91.215(AAM)
- Class D Airspace
- Class E (shd) Airspace
- Class E Airspace with floor 700 ft. above surface.
- Class E Airspace with floor 1500 ft. or greater above surface that abuts Class G Airspace.
- Differentiates floors of Class E Airspace greater than 700 ft. above surface unless otherwise designated as shown above.
- Class E Airspace exists at 1200' AGL, unless otherwise designated as shown above.

Class E Airspace low altitude Federal Airways are indicated by center line. Intersection - Arrows are directed towards facilities which establish intersection.

Total mileage between NADADs on direct Airways.

Prohibited, Restricted, Warning and Alert Areas Canadian Advisory and Restricted Areas

MOA - Military Operations Areas

Special Airport Traffic Area (See F.A.R. Part 93 for details)

### TOPOGRAPHIC INFORMATION

- Roads
- Road Markers
- Bridges And Viaducts
- Power Transmission Lines
- Aerial Cable
- Landmark Feature - stadium, factory, school, golf course, etc.
- Outdoor Theatre
- Lookout Tower P-17 (Site Number) 613 (Elevation Base of Tower)
- Coast Guard Station
- Race Track
- Tank - water, oil or gas
- Oil Well
- Mines And Quarries
- Mountain Pass 11823 (Elevation of Pass)

(Pass symbol does not indicate a recommended route or direction of flight and pass elevation does not indicate a recommended clearance altitude. Hazardous flight conditions may exist within and near mountain passes.)

### OBSTRUCTIONS

- 1000 ft. and higher AGL
- below 1000 ft. AGL
- Group Obstruction
- Obstruction with high-intensity lights May operate part-time
- Elevation of the top above mean sea level
- Height above ground
- Under construction or reported - position and elevation unverified

NOTICE: Guy wires may extend outward from structures.

### MISCELLANEOUS

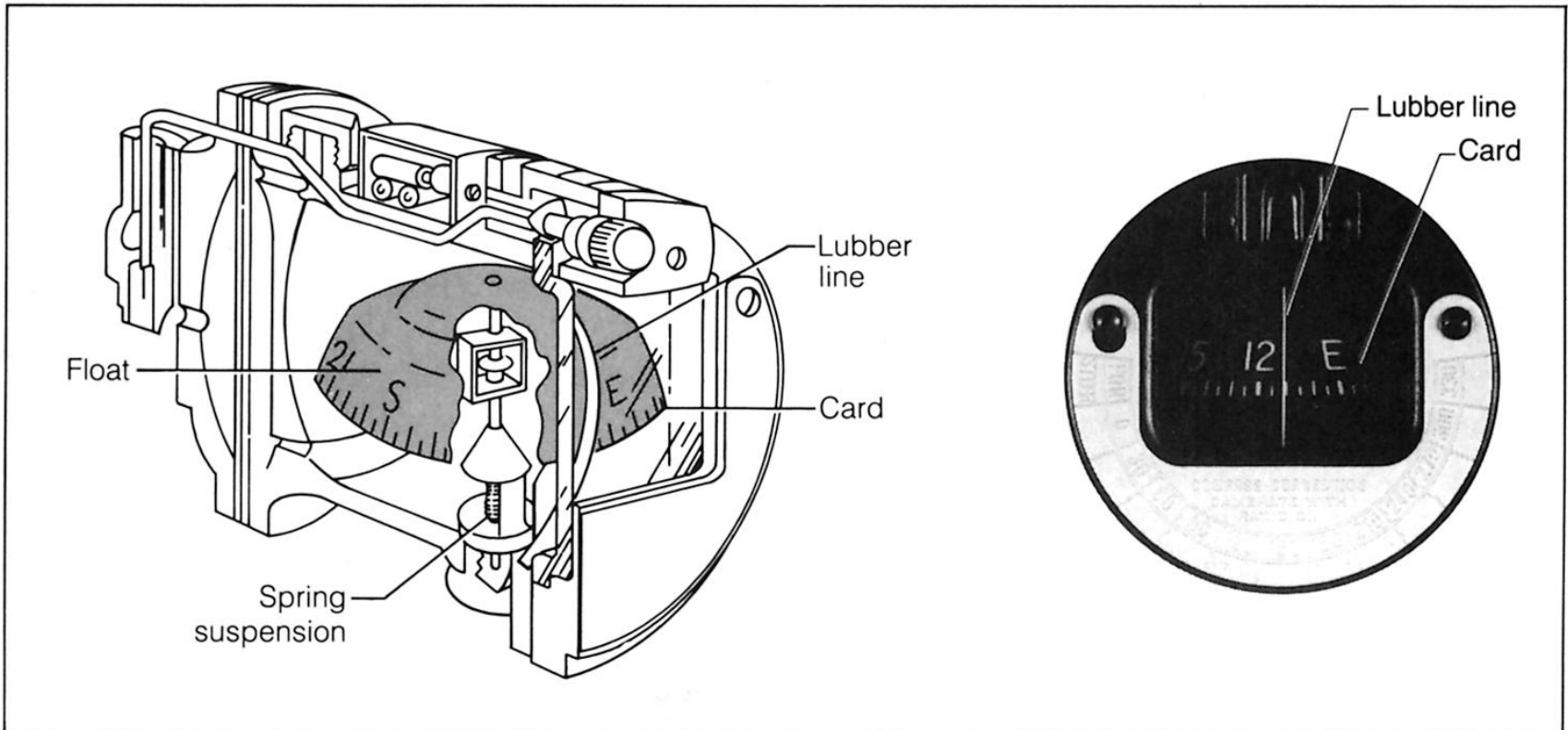
- Unlighted Activity
- Flashing Light
- Hang Glider Activity
- Gader Operations
- Parachute Jumping Area (See Airport Facility Directory)
- VPKYZ VFR Waypoints (See Airport Facility Directory for latitude/longitude)
- Marine Light



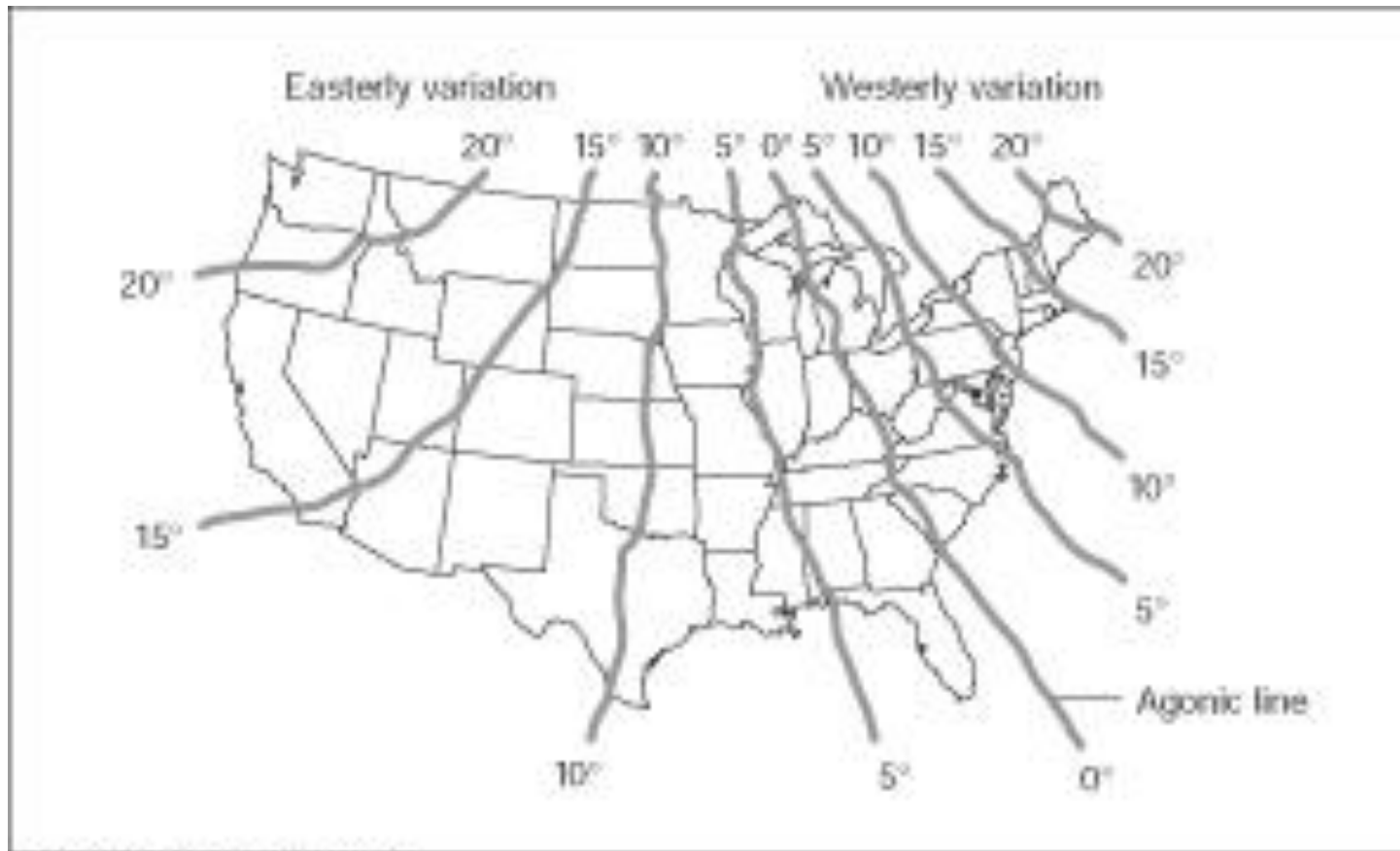
# Aircraft Instruments – Magnetic Compass

- Aircraft heading is required to navigate using charts
  - Aeronautic charts drawn to True North
- Use Magnetic compass
- Magnetic compass points to Magnetic North (not True North) due to Magnetic Variation of earth
- Magnetic Variation = True North and Magnetic North
- In U.S. variation ranges from 0 to 20 degrees
- Magnetic compass subject to inaccuracies due to:
  - Aircraft accelerations
  - Aircraft turns
  - Stray magnetic fields of aircraft electrical equipment (e.g. windshield heater)

# Aircraft Instruments – Magnetic Compass



# Aircraft Instruments – Magnetic Compass – Magnetic Variation



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# Aircraft Instruments – Heading Indicator

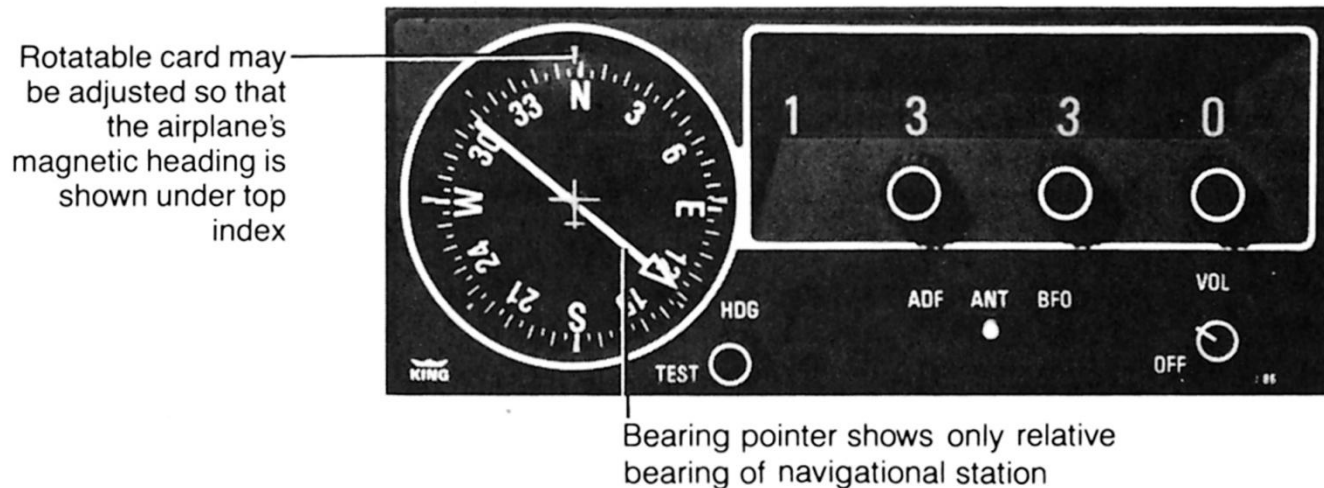
- Heading indicator uses spinning gyroscope
- Initialized prior to takeoff using compass rose
- Subject to drift, must be reset during flight
- Possible inaccuracies:
  - Initialization errors
  - Internal bearing friction
  - Drift
  - Mechanical failures



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# Electronic Navigation – Non-Directional Beacon

- NDB transmits radio signal
  - Omni-directional signal
  - Low-medium frequency (190 – 540 kHz)
- Automatic Direction Finder (ADF) on aircraft
  - Displays (relative) bearing to the NDB
- Nowadays, located at smaller airports as instrument approach aids



# Electronic Navigation - VOR

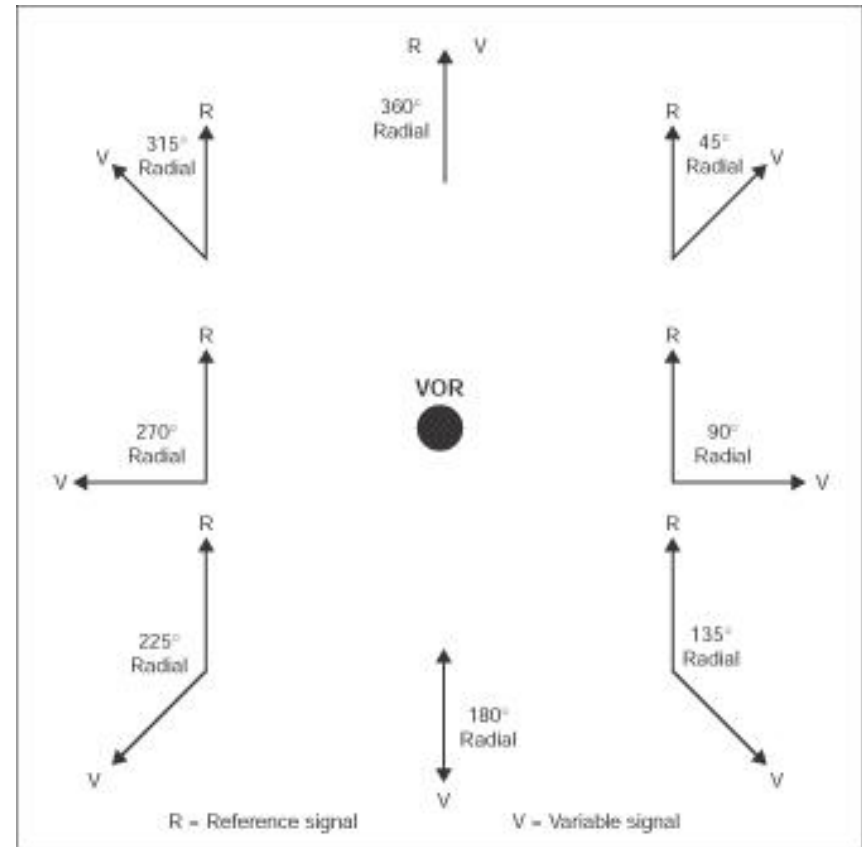
- VOR ground station transmits navigation courses (radials) around the compass
- Each VOR assigned a radio frequency 108.10 to 117.90 MHz
  - Adjacent VORs have different frequencies
- VOR ground-station



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# VOR - Operation

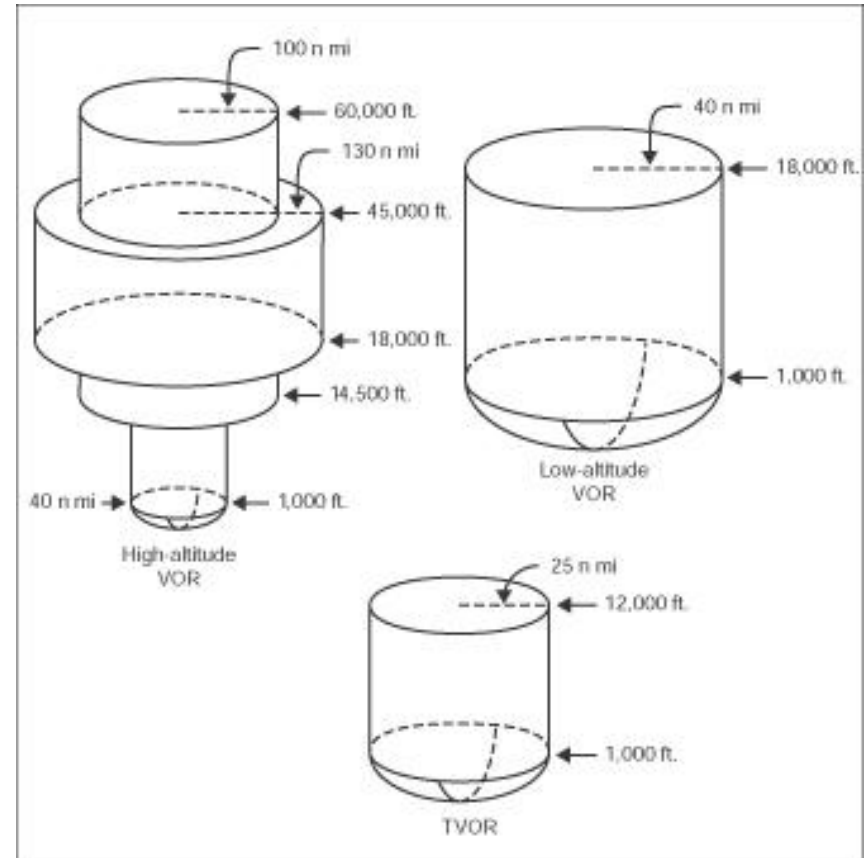
- VOR transmits two signals:
  - Reference signal (constant in all directions)
  - Variable-phase signal (phase varies with azimuth)
- VOR Course is determined by difference in phase between Reference and Variable-phase signals
  - At Magnetic North, Variable-phase is in phase with Reference signal
  - At Magnetic South, Variable-phase is 180 out of phase with Reference signal



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# VOR Service Volumes

- High-altitude VORs
  - Frequency 112.00 to 117.90 MHz
  - 200 nautical mile range, between 18,000 and 60,000 feet
- Low-altitude VORs
  - Frequency 108.10 to 111.80
  - 40 nautical mile range, below 18,000 feet
- Terminal VORs
  - 2.5 nautical mile range

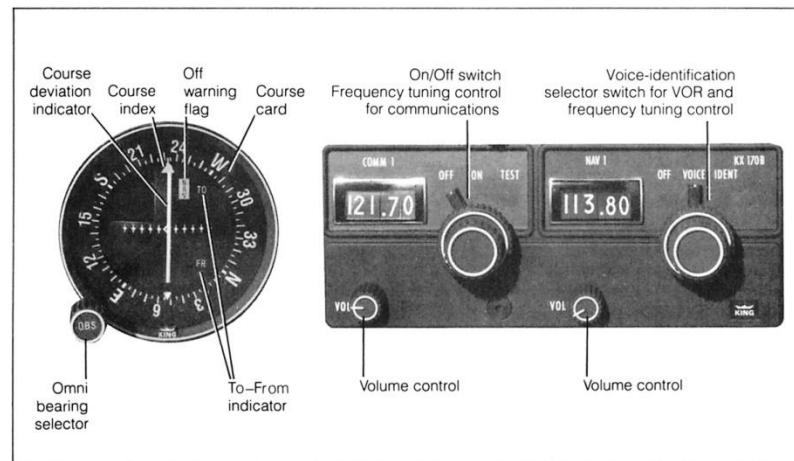


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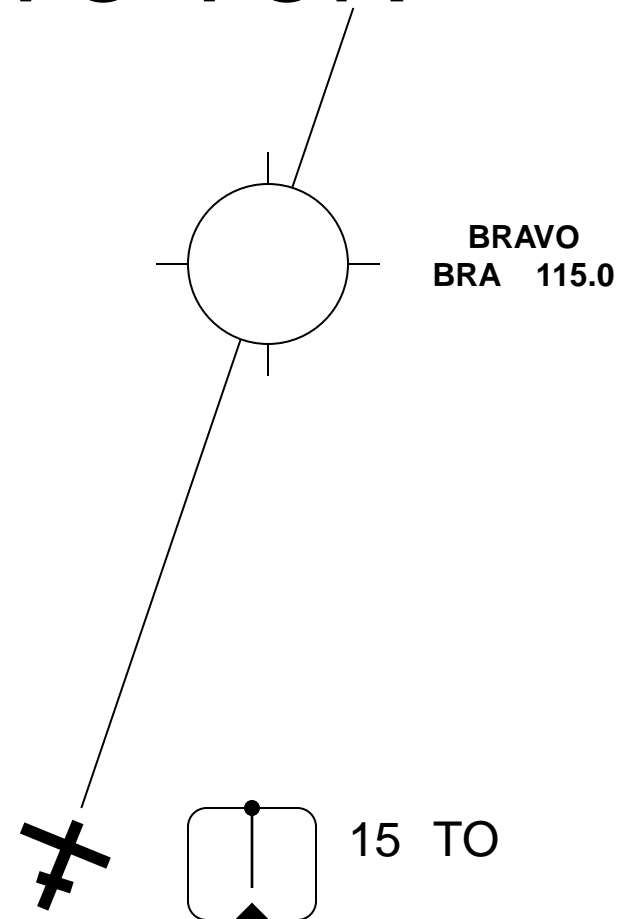
# Using VOR in Cockpit

- Dial in VOR frequency
- Dial in desired VOR course using Omni-bearing Selector (OBS)
- Device shows TO or FROM flag
- Device shows if aircraft to the left or right of desired course (OBS course)
  - Known as (lateral) *deviation indicator*



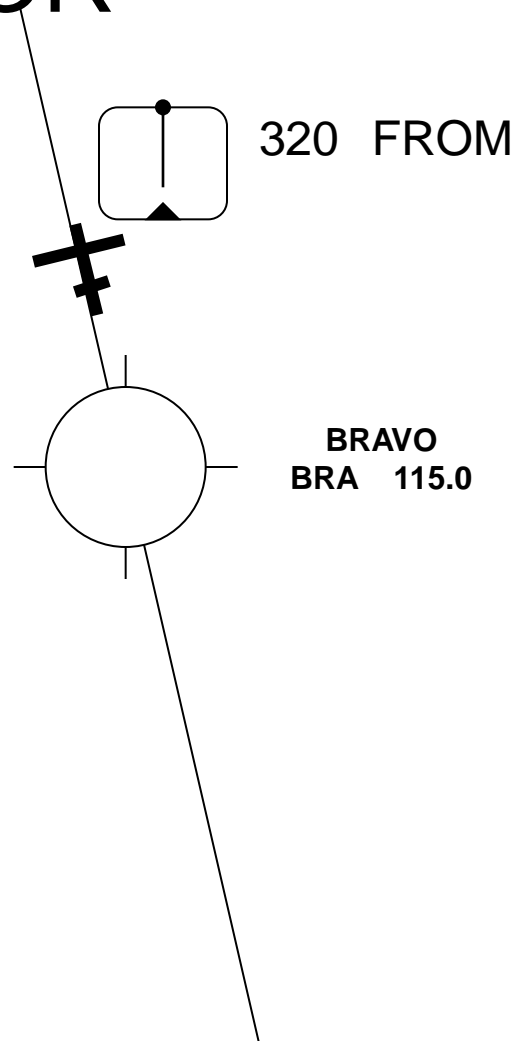
# ATC: “From present position, DIRECT TO BRAVO VOR”

1. Tune the VOR
2. Identify the VOR (Morse Code)
3. Rotate OBS until left-right needle is centered AND To-From Indicator is TO
4. Number is Course to VOR (inbound)
  - Inbound Course (195 ) is reciprocal of Radial
5. Turn and fly heading, keep needle centered



# ATC: “From present position intercept and fly outbound on 320 radial from BRAVO VOR”

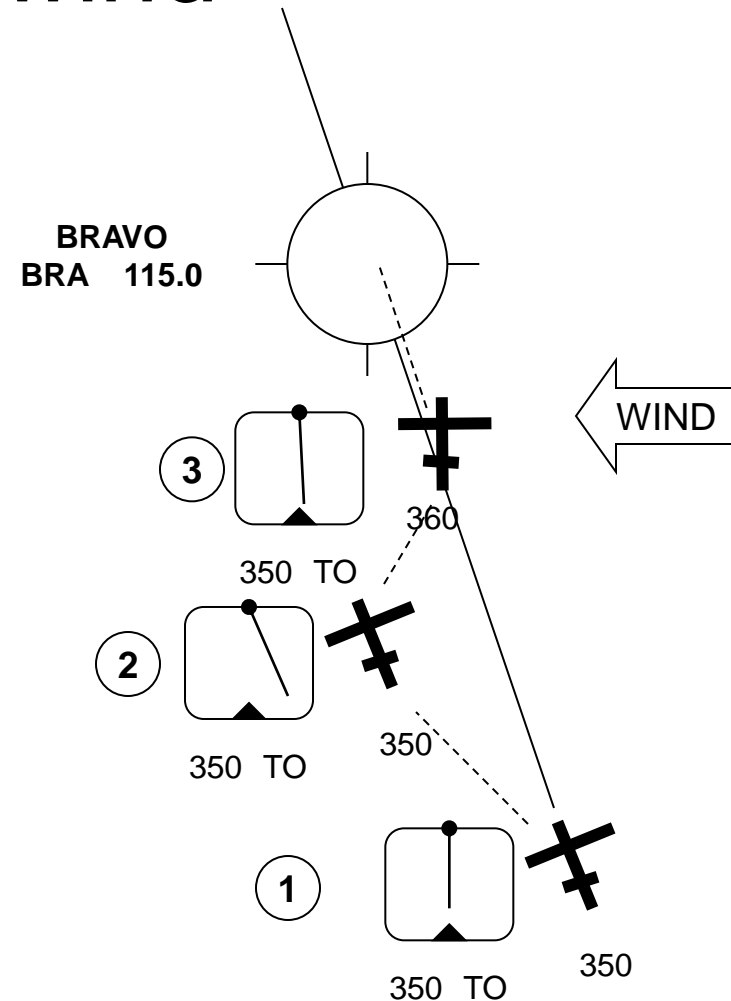
1. Tune and identify station
2. Select 320 on OBS
  - Outbound: Course = Radial
3. To-From Indicator is FROM



# ATC: “Cleared direct BRAVO”

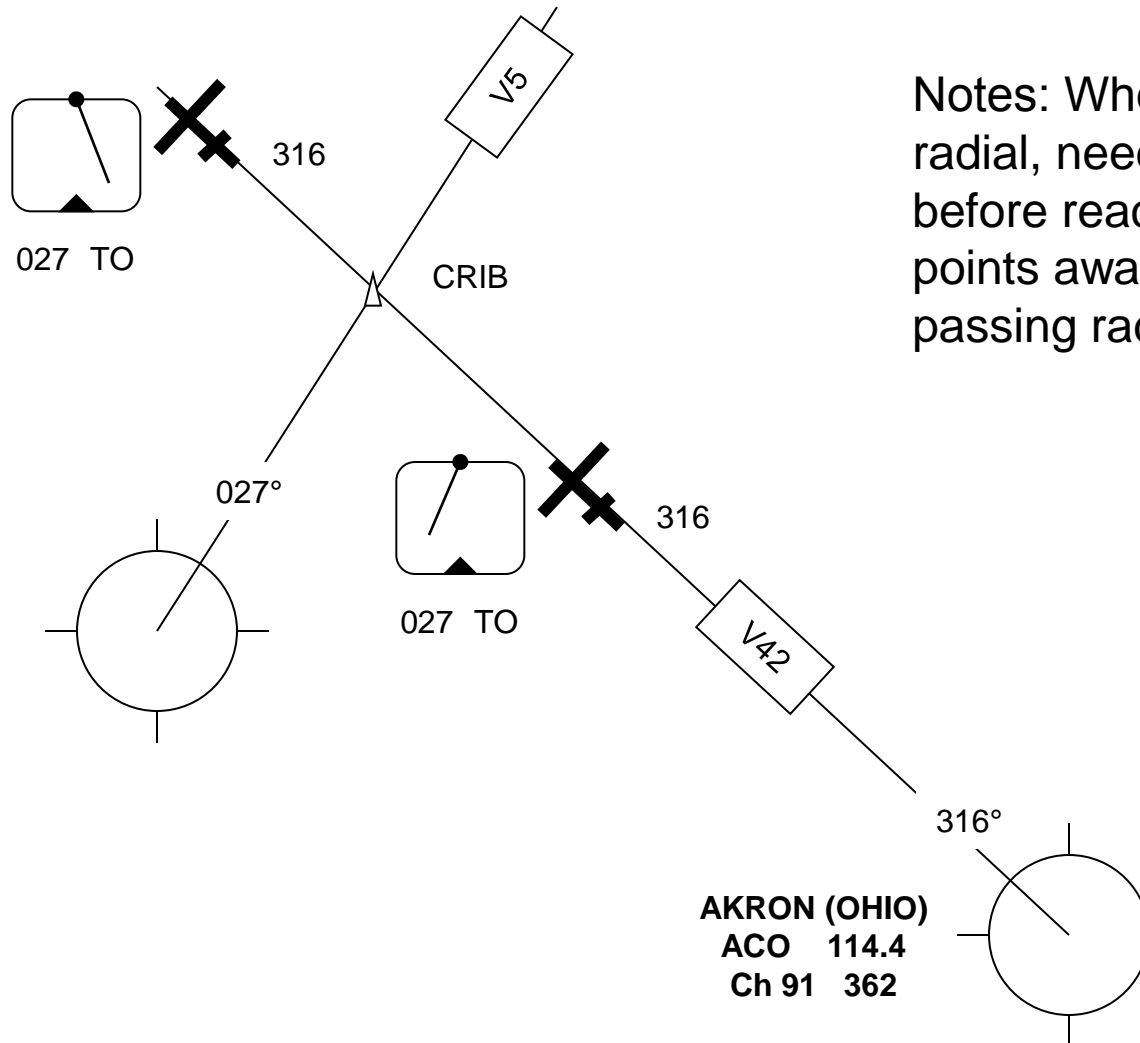
## 20 knot cross wind

1. Tune and identify VOR and steer heading  $350^\circ$
  2. If heading  $350^\circ$  is maintained, aircraft will drift to left of  $350^\circ$  radial
  3. Turn and fly heading  $360^\circ$  until needle centered
- Repeat “bracketing” maneuver until find heading to compensate for crosswind



# Flying V42 airway.

## ATC: "Report crossing CRIB Intersection"



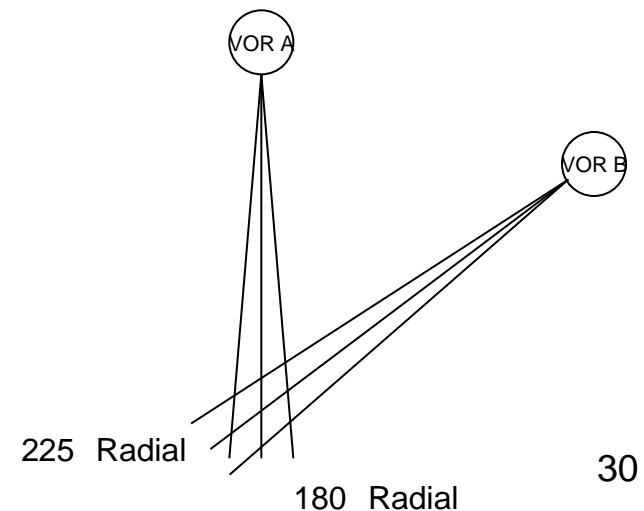
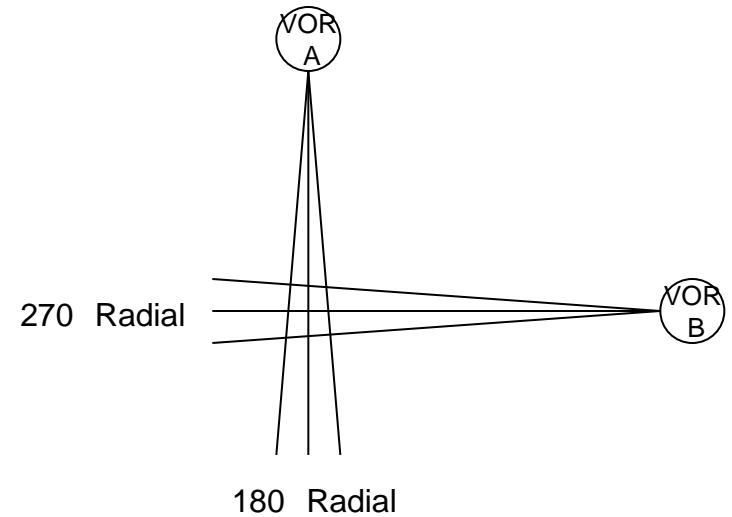
Notes: When tuning "side" radial, needle points to VOR before reaching radial (needle points away from VOR after passing radial)

CLEVELAND  
CLE 113.6  
Ch 83 344

AKRON (OHIO)  
ACO 114.4  
Ch 91 362

# Theta-Theta Position Computation

- Pilot obtain bearing from two VORs
- Plot lines from each VOR
- Intersection is location of aircraft
- Best VOR geometry is 90
  - VOR receiver accurate to +/- 6
  - Smallest intersection area is when VORs at right angles

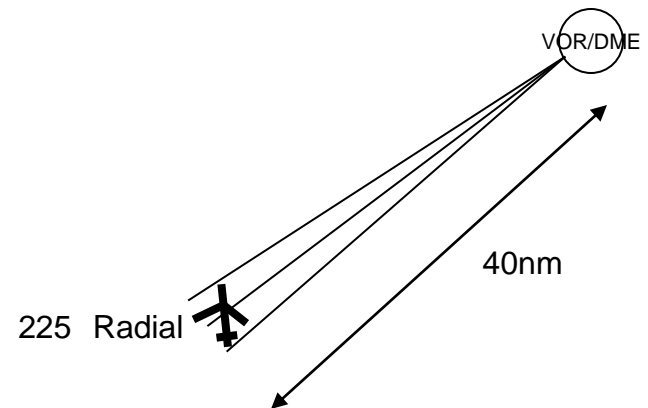


# Distance Measuring Equipment (DME)

- DME provides aircraft distance to ground-station
  - Slant-range distance
- Interrogator on aircraft transmits pulsed interrogation signal
- Transponder on ground responds to interrogator signal
- Elapsed Range Time is computed
- Range Time for signal to travel 1 nm is 12.36 microseconds
- Slant Range = (Interrogator Time – Reception of Transponder Time) / 12.36 micro-seconds

# Rho-Theta Position Computation

- Position is based on Bearing from VOR and Distance from DME
- VOR and DME co-located at know location





# Airways

- Airways defined by radials between VORs
- Airways dimensions
  - 4nm on either side of center-line
  - Spread-out due to VOR radials
- Changeover Point (COP)
  - Fix between two navigational aids where pilot ceases to track radial FROM VOR and starts to track radial TO VOR
- Airways designated with identifying numbers
  - Preceded by V (Victor), if low altitude
  - Preceded by J (Jet), if high altitude

# MEAs and MOCAs

- Minimum En-route Altitude (MEA)
  - Designated for each airway
  - Aircraft operating above MEA guaranteed clear on obstruction, terrain
  - Guaranteed proper VOR reception (200nm or 40nm)
- Minimum Obstruction Clearance Altitudes (MOCAs)
  - Designated for some airways
  - Less than MEAs
  - Used in case of emergency require lower altitude
  - Guaranteed proper VOR reception only if within 22nm of VOR

# Global Navigation Satellite System (GNSS)

- GNSS (GPS in US)
  - Min 21 operational satellites in orbit
    - + 3 spares
  - GPS computes:
    - Position (latitude/longitude)
    - Altitude
    - Velocity (ground speed)
    - Time

# GPS Operation

- Position computation based on ranging and triangulation
  - GPS receiver on aircraft measures distance from satellite to aircraft using (fixed) travel time of a radio signal
  - Satellite transmits Course/Acquisition (C/A) code with info on satellite position (=ephemeris)
  - GPS compares actual time with Satellite transmitted time and uses difference to compute distance (= pseudo-range)
- GPS requires distance from 3 satellites (+ time from fourth)

# GPS Accuracy

- Receiver Autonomous Integrity Monitor (RAIM)
  - Independent means to determine if satellite is providing corrupted information
  - Requires data from 5<sup>th</sup> satellite

# WAAS

- Wide Area Augmentation System (WAAS)
  - Differential GPS signal
  - 35 ground-reference stations
    - Accurately surveyed location
    - Receive signals from satellites
    - Determine errors
    - Corrections broadcast from geo-stationary satellite above US
- Used for all enroute navigation
  - Also Category I approaches

# LAAS

- Local Area Augmentation System (LAAS)
  - Complement WAAS for Cat II, Cat III approaches
  - Transmits correction information from airport to 30nm radius

# Inertial Navigation System

- Equipment on aircraft
- Computes position (3-D) and velocities
  - Computations based on accelerometers and angular rate gyros
  - Initialized with lat/lon prior to flight in stationary position
  - Accelerations measured and integrated to yield velocities, integrated to yield position
  - Very expensive units accurate to +/-2.5nm for 14 hour flight
- Used for en-route navigation in conjunction with radios and GPS



# Inertial Navigation Systems

- Measures accelerations in 3-D space
  - Integrate accelerations to get velocities
  - Integrate velocities to get position
- INS records movement relative to Celestial Sphere (not Earth)
  - Mount INS and turn on.
  - Hour later, INS has not moved, accelerometers have detected earth's rotation
- Drift
  - Any errors in accelerations amplified in velocities and position
  - Compensating for errors, leads to designs for  $< 0.8\text{nm/hr}$
- Schuler Drift
  - 84 minute periodic error (period of pendulum length of diameter of Earth)
  - Over long time, error nulls itself

# Homework

1. Describe the difference between dead-reckoning and pilotage
2. Using VFR Chart VFR Terminal Area Chart: Baltimore-Washington
  - Describe Airport SHANNON
  - Describe VOR BROOKE
  - Describe Airway V286
3. Describe the operation of GNSS to determine aircraft position
4. What are the basic principle(s) of operation of WAAS and LAAS
5. What are the limitations of GNSS

Prepare for quiz (fill in the blank, multiple choice) next class