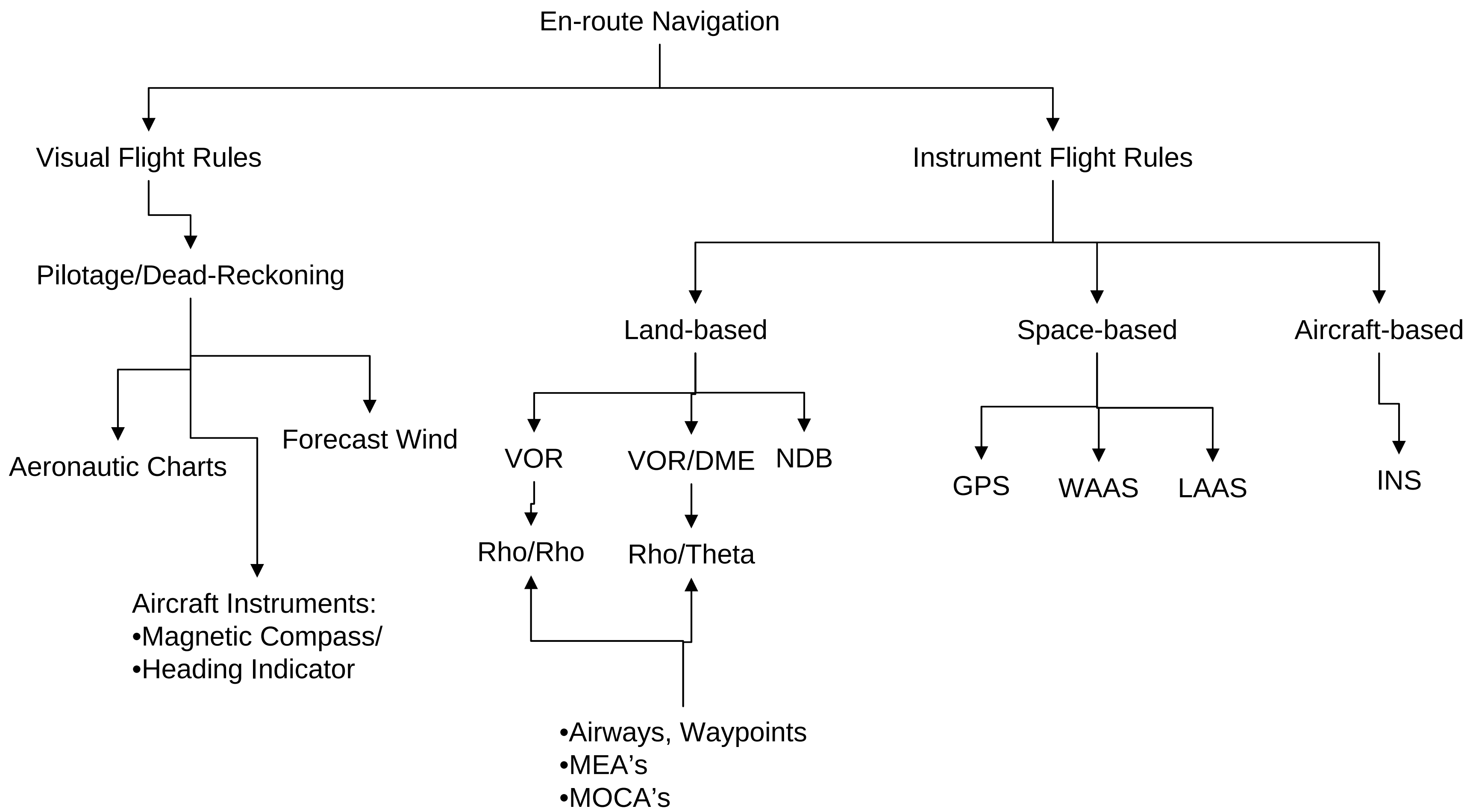
Navigation Systems - Enroute

Nolan, Chap 2


En-route Navigation
Visual Flight Rules
Instrument Flight Rules
Pilotage/Dead-Reckoning
Aeronautic Charts
Forecast Wind
Aircraft Instruments:
•Magnetic Compass/
•Heading Indicator
Land-based
Space-based
Aircraft-based
VOR
VOR/DME
NDB
Rho/Rho
Rho/Theta
•Airways, Waypoints
•MEA's
•MOCA's
GPS
WAAS
LAAS
INS

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

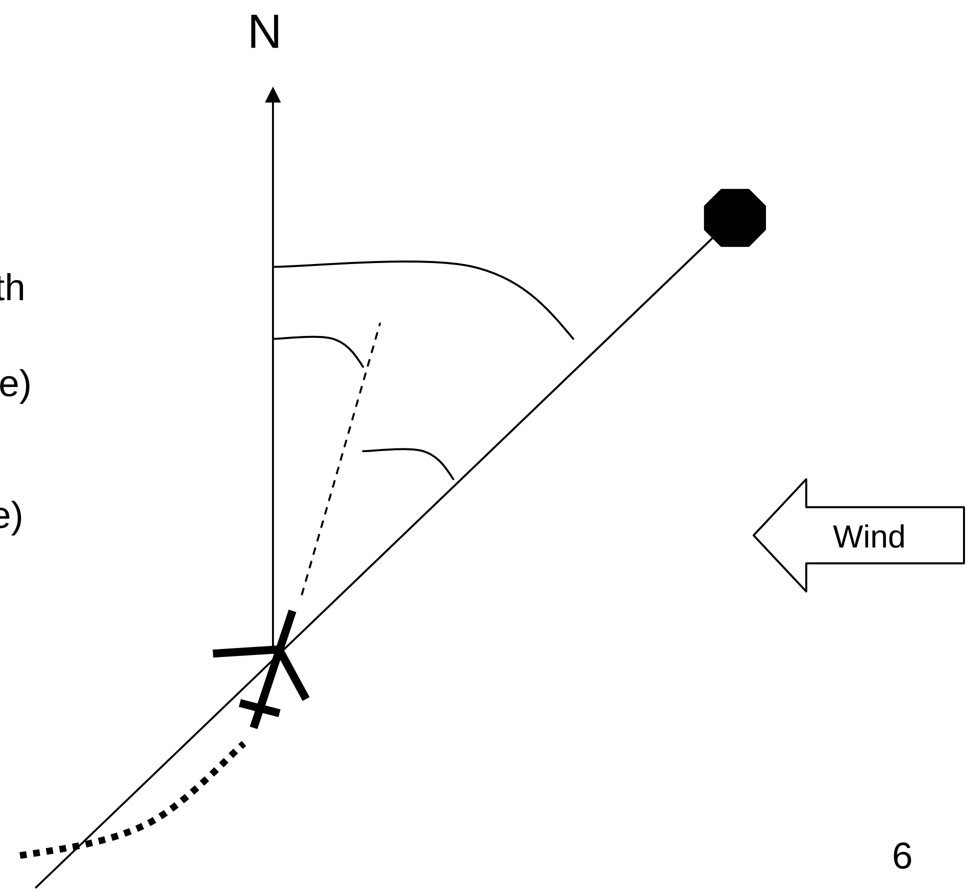
- Determine position in 4-D space
  - Latitude/Longitude
  - Altitude (ft)
  - Time (Greenwich Mean Time – GMT, Zulu Time)

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

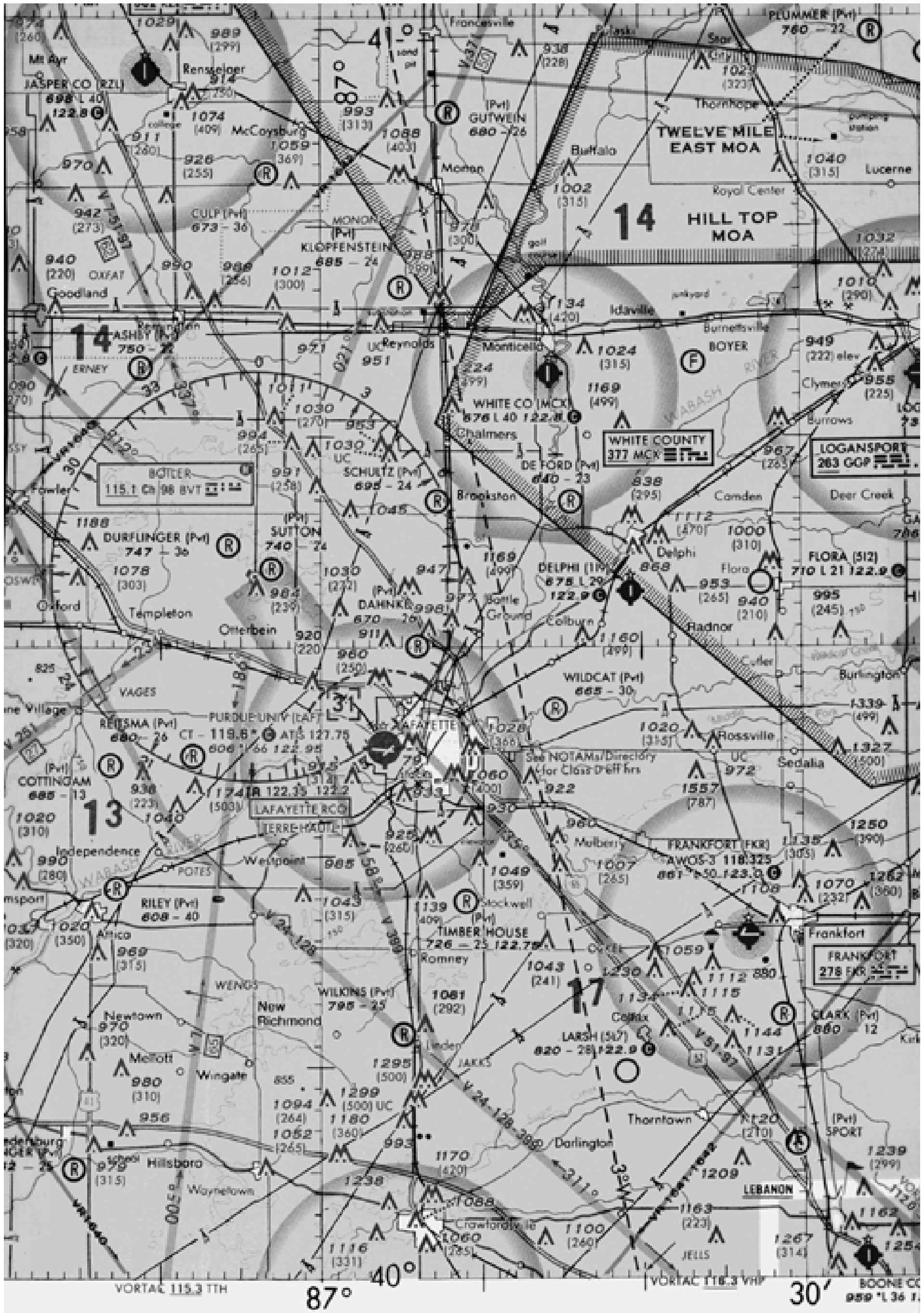
- Use map of surrounding area as a reference
- Draw line on map for route
  - Identify landmarks to use as reference
- Adjust aircraft course to fly to landmarks
- Adjust aircraft course to compensate for crosswinds
- Trial-and-Error

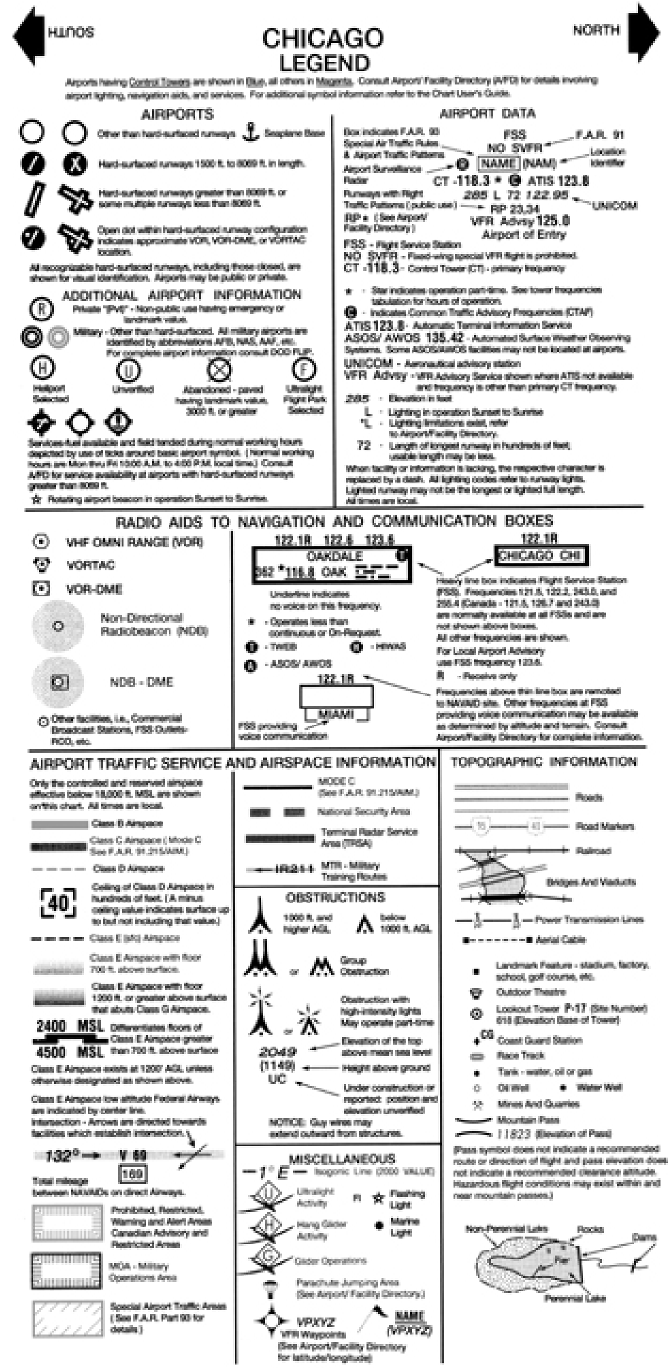
Visual Navigation – Dead Reckoning

- 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




SOUTH
NORTH
CHICAGO
LEGEND
AIRPORTS
AIRPORT DATA
ADDITIONAL AIRPORT INFORMATION
RADIO AIDS TO NAVIGATION AND COMMUNICATION BOXES
VHF OMNI RANGE (VOR)
VORTAC
VOR-DME
Non-Directional Radiobeacon (NDB)
NDB - DME
OAKDALE
CHICAGO CHI
MIAMI
AIRPORT TRAFFIC SERVICE AND AIRSPACE INFORMATION
TOPOGRAPHIC INFORMATION
OBSTRUCTIONS
MISCELLANEOUS

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

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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

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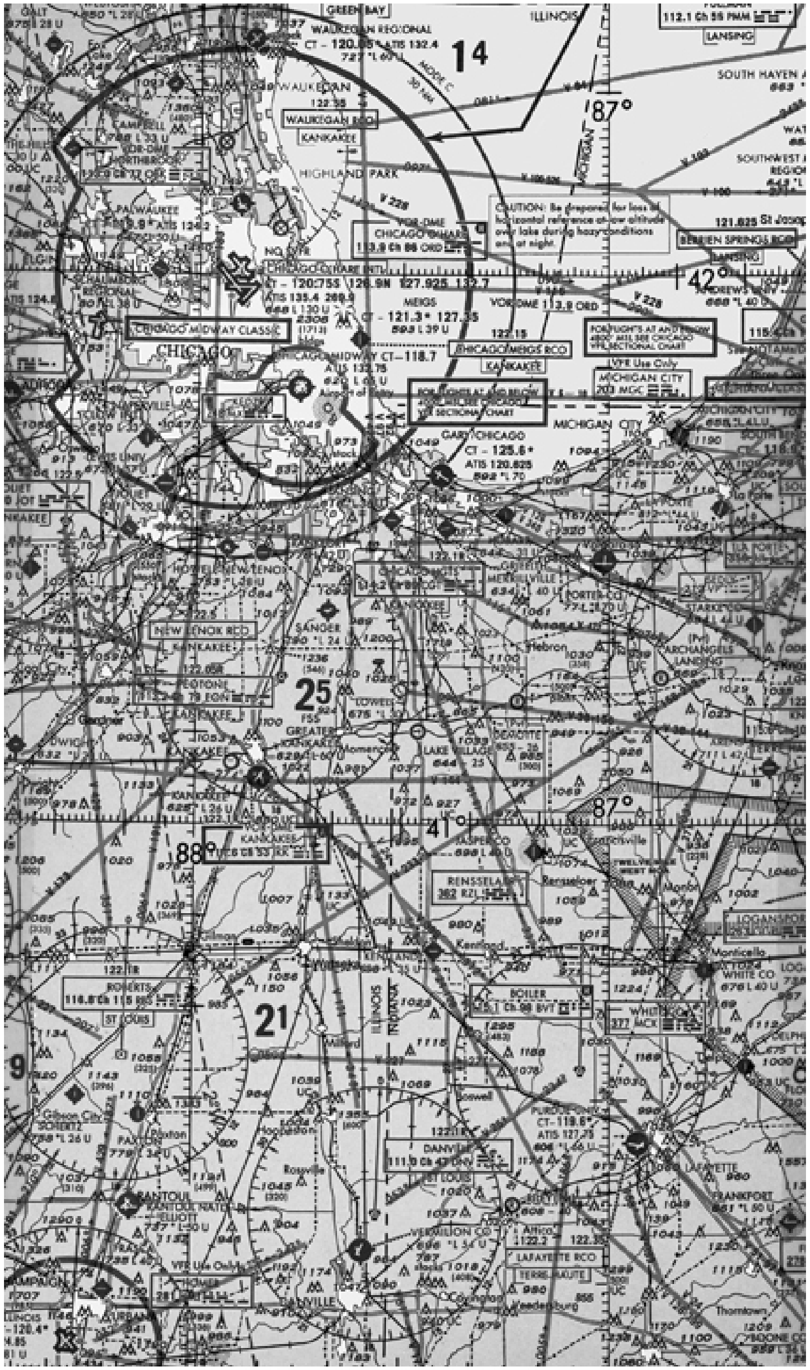
Airway – Victor 7

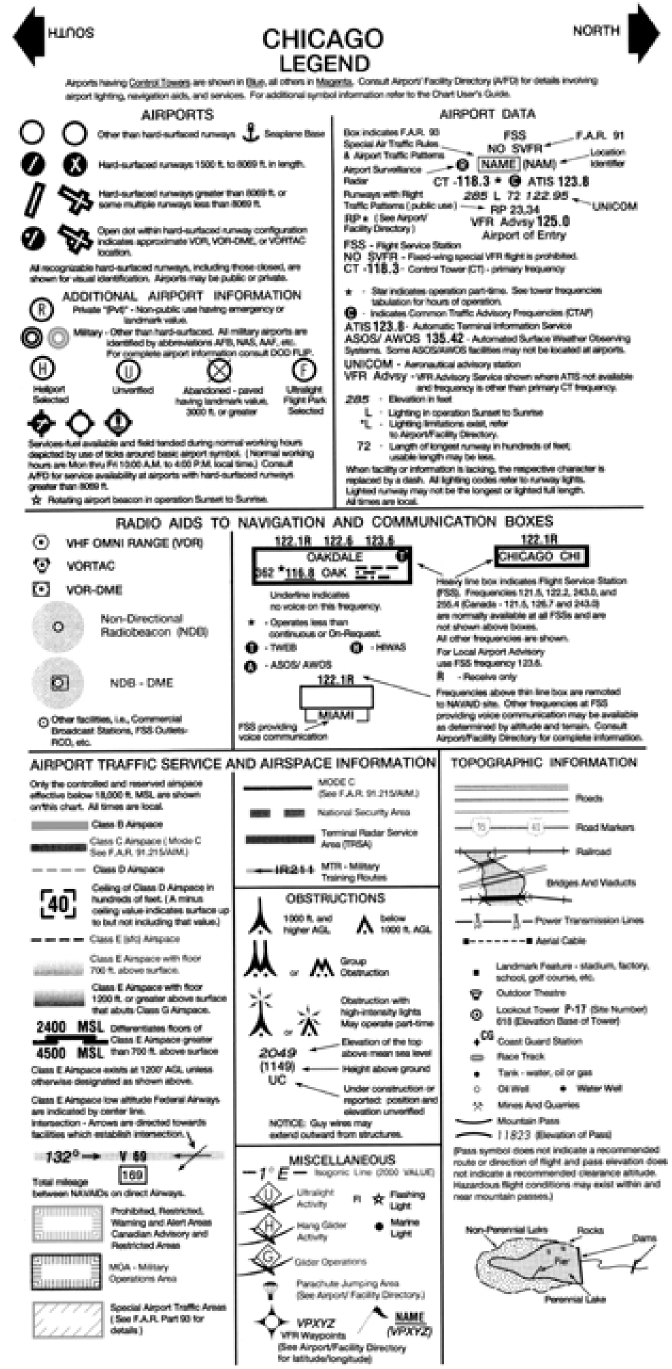
- Airway Name – Victor 7
- 65 nm between VORTAC TTH and VORTAC BVT
- Fly northbound on 5 degree Radial from TTH
- Fly southbound on 186 Radial from BVT
- WENGS Intersection using Radials from BVT and <not shown>

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



14
87°
42°
CHICAGO
25
41°
88°
21



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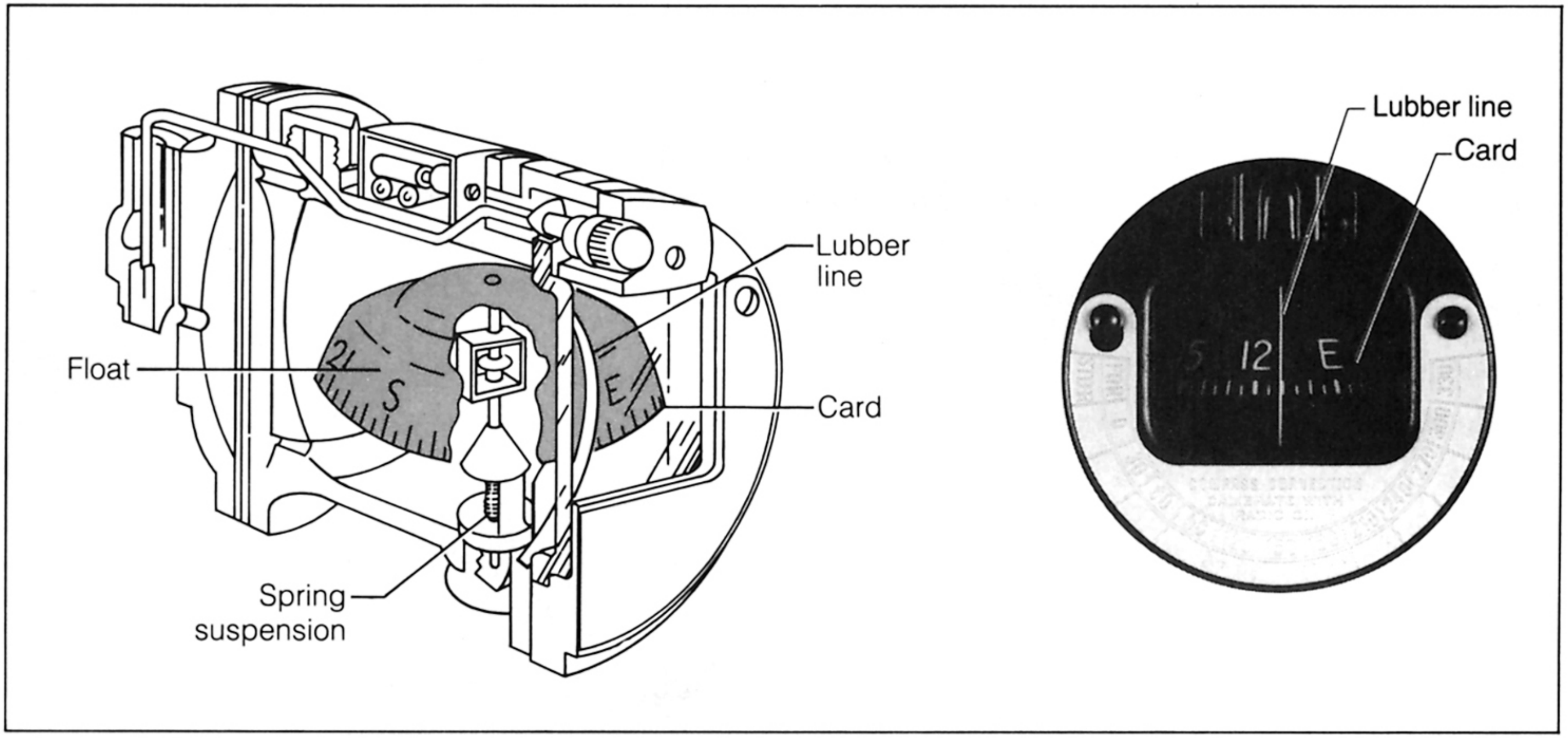
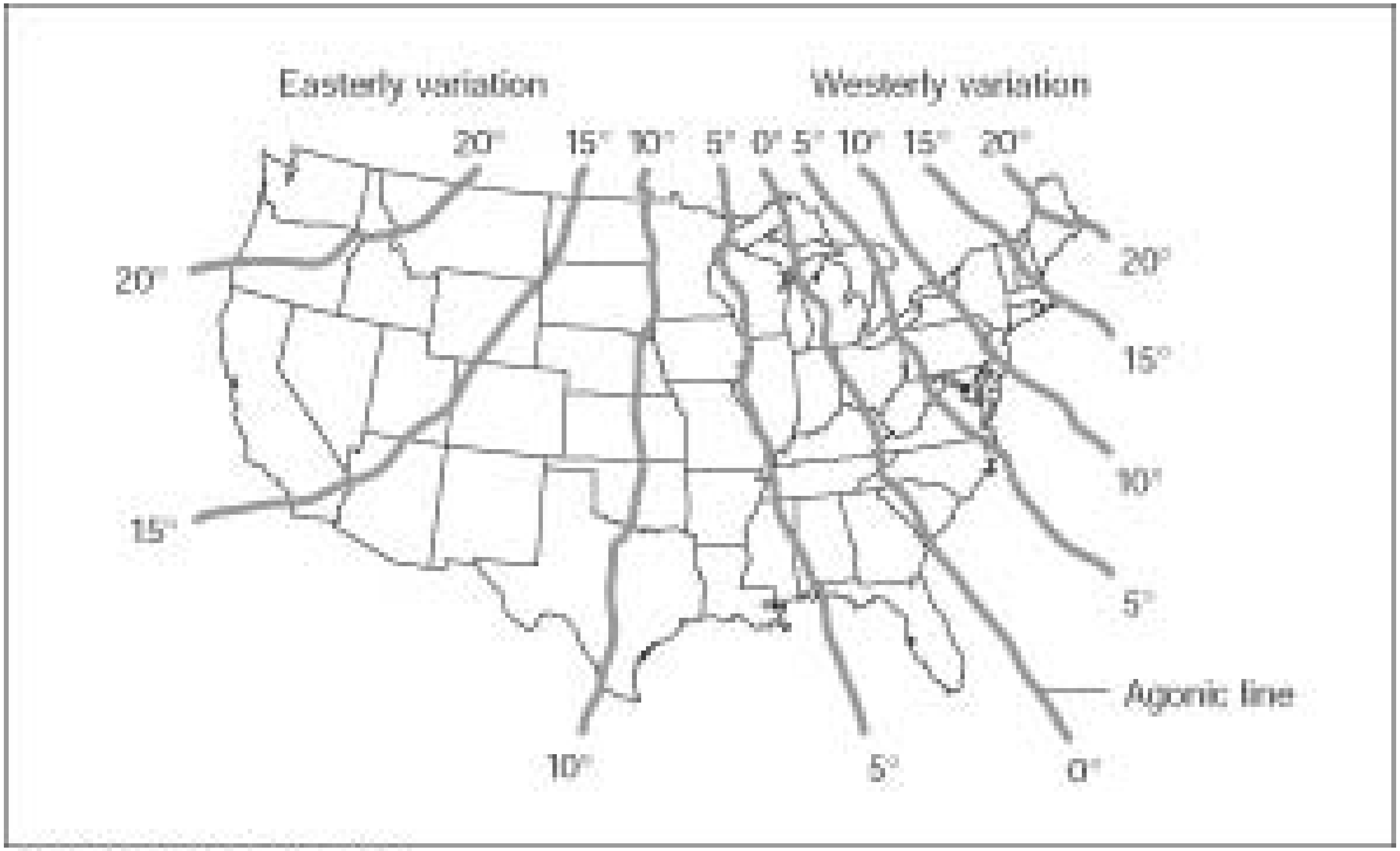
Aircraft Instruments – Magnetic Compass

- 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



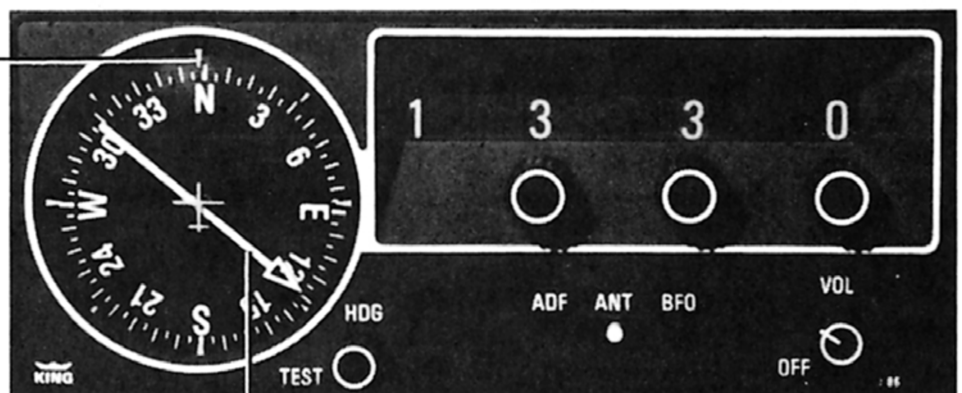
Aircraft Instruments – Heading Indicator

- 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

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
- Nowdays, located at smaller airports as instrument approach aids

Rotatable card may be adjusted so that the airplane's magnetic heading is shown under top index



Bearing pointer shows only relative bearing of navigational station

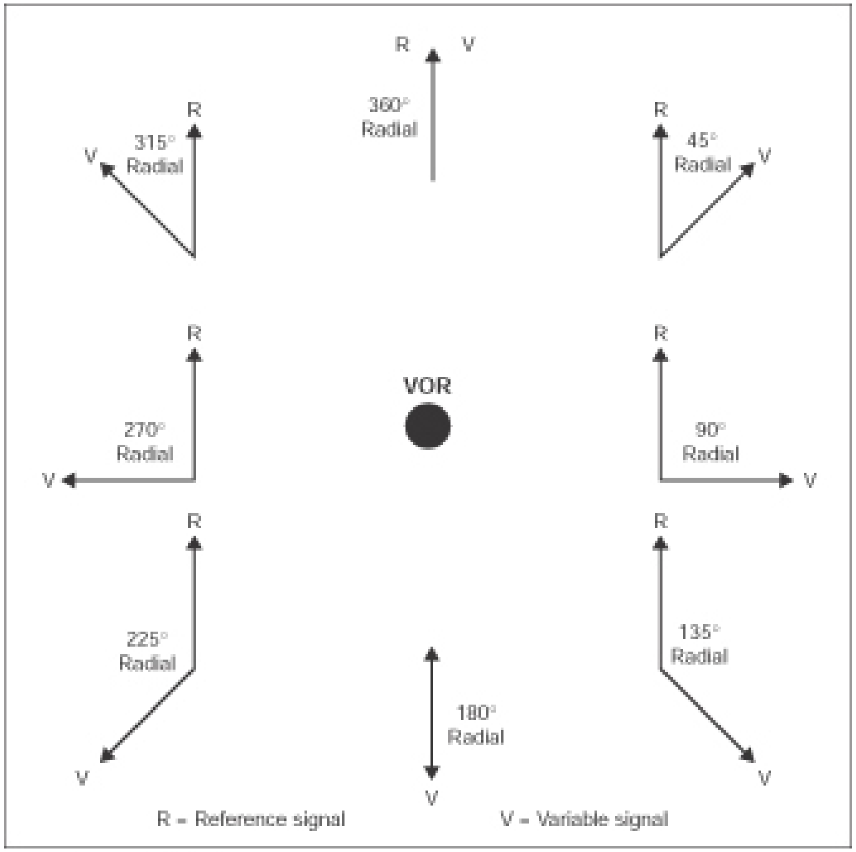
Electronic Navigation - VOR

- 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

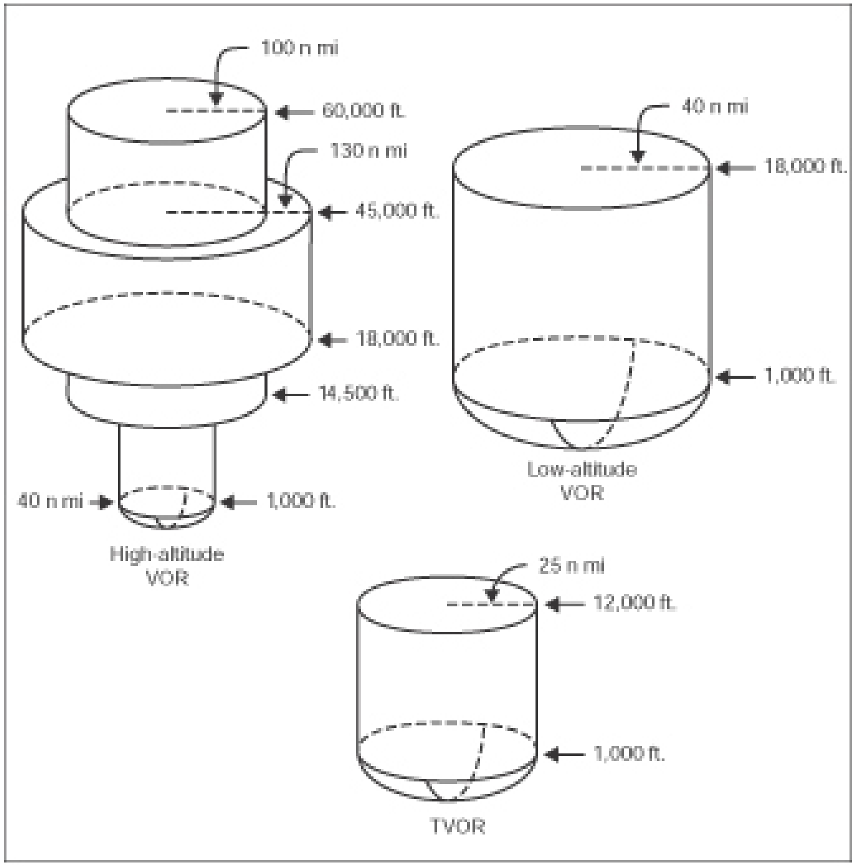
VOR - Operation

- 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



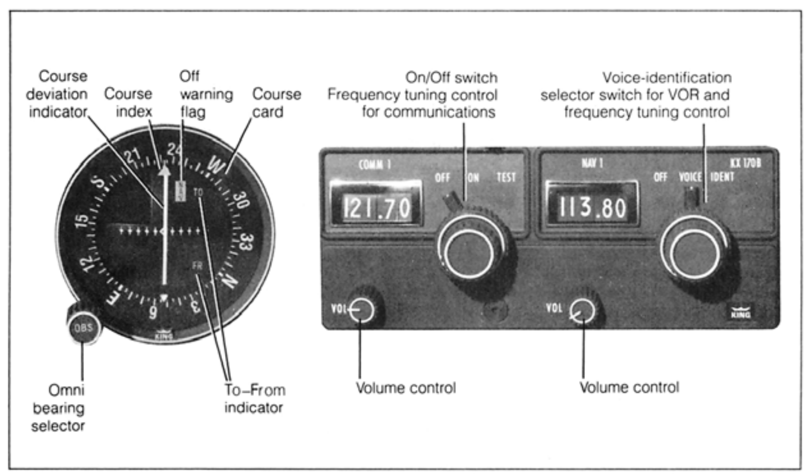
VOR Service Volumes

- 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



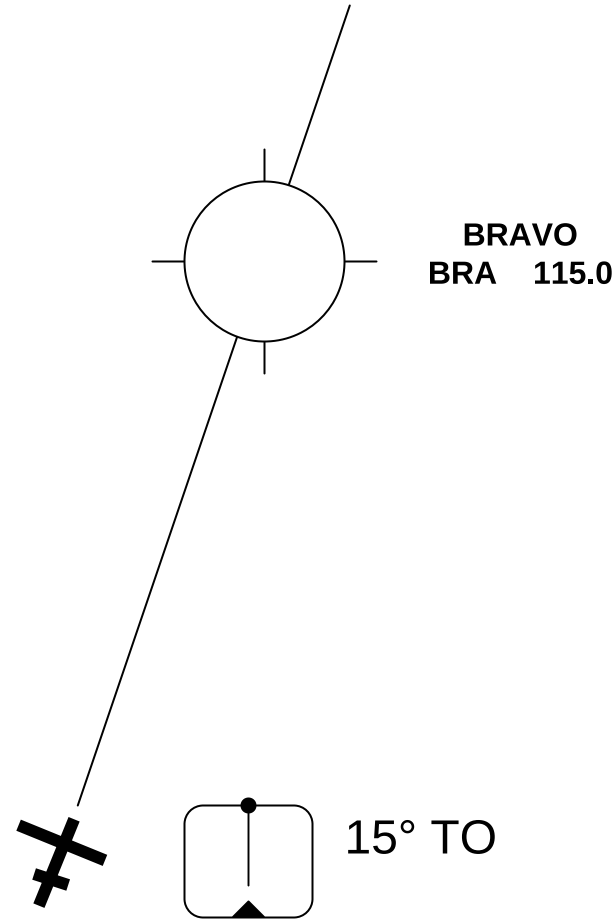
Using VOR in Cockpit

- 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*



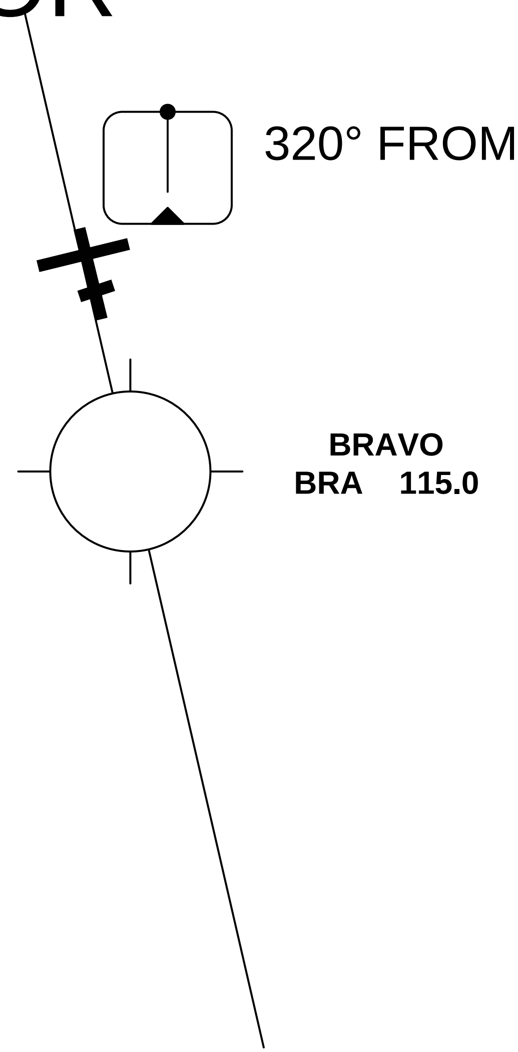
ATC: "From present position, DIRECT TO BRAVO VOR"

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”

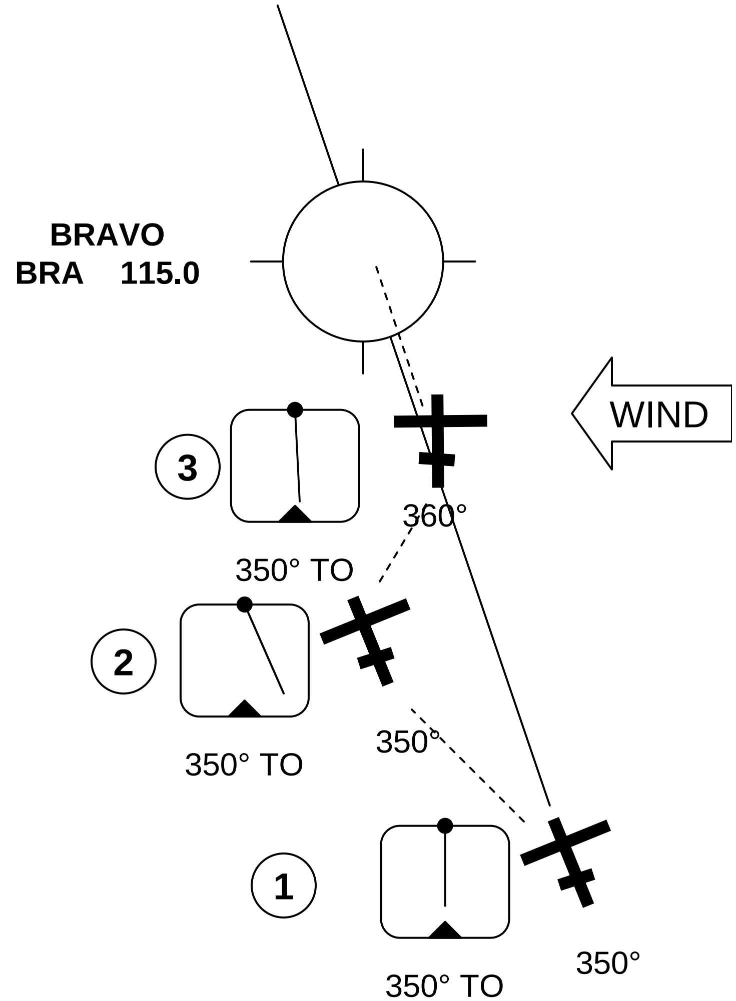
1. Tune and identify station
2. Select 320 on OBS
   – Outbound: Course = Radial
3. To-From Indicator is FROM



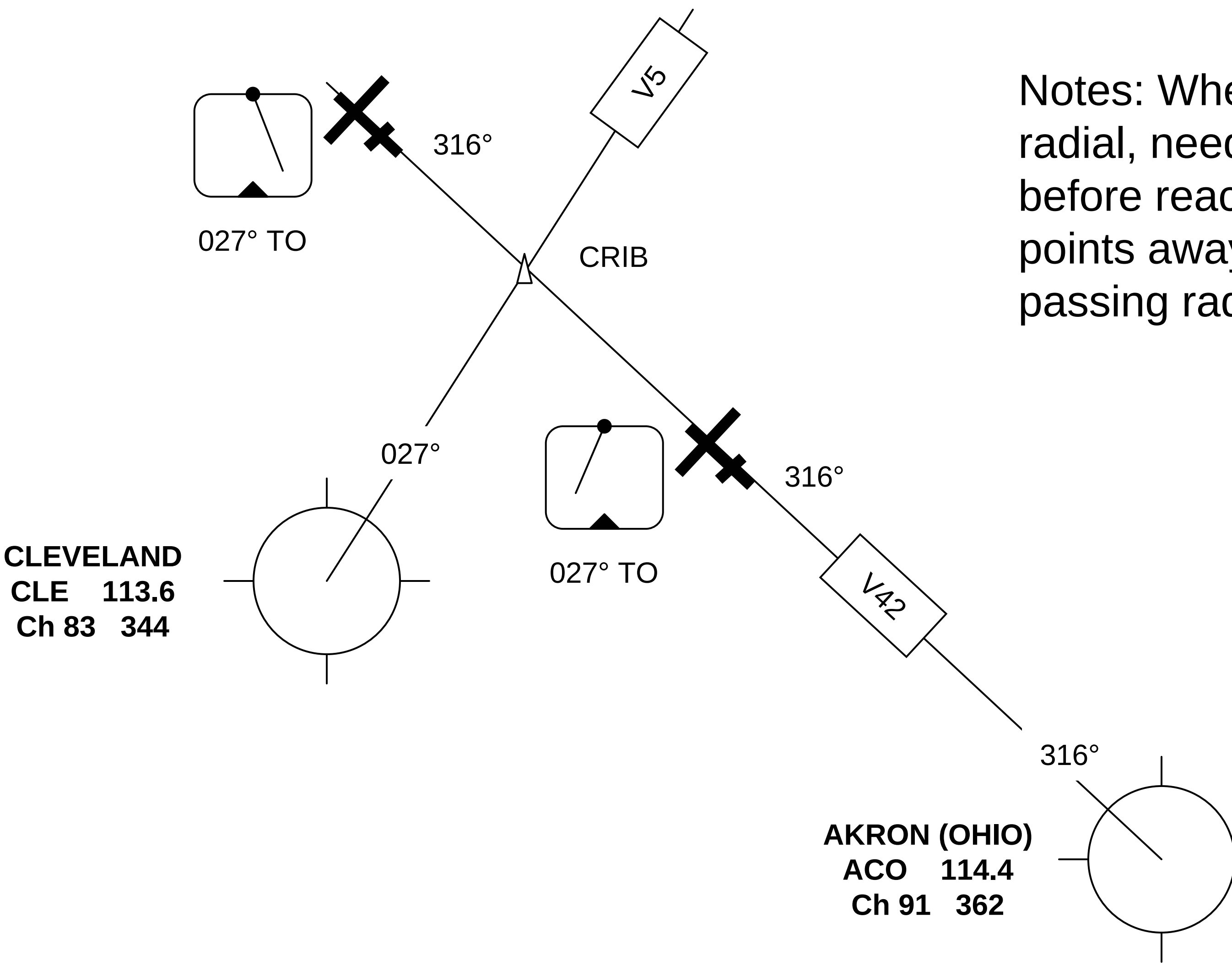
ATC: "Cleared direct BRAVO" 20 knot cross wind

1. Tune and identify VOR and steer heading 350°
2. If heading 350° is maintained, aircraft will drift to left of 350° radial
3. Turn and fly heading 360° until needle centered

- Repeat "bracketing" maneuver until find heading to compensate for crosswind



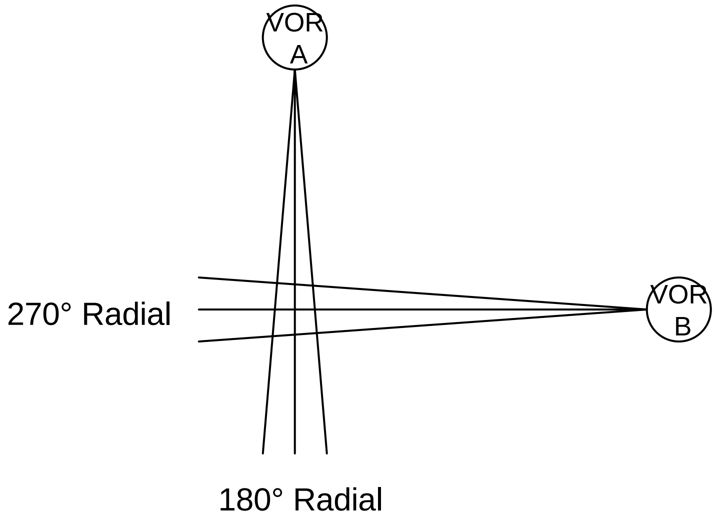
Flying V42 airway.
ATC: “Report crossing CRIB Intersection”

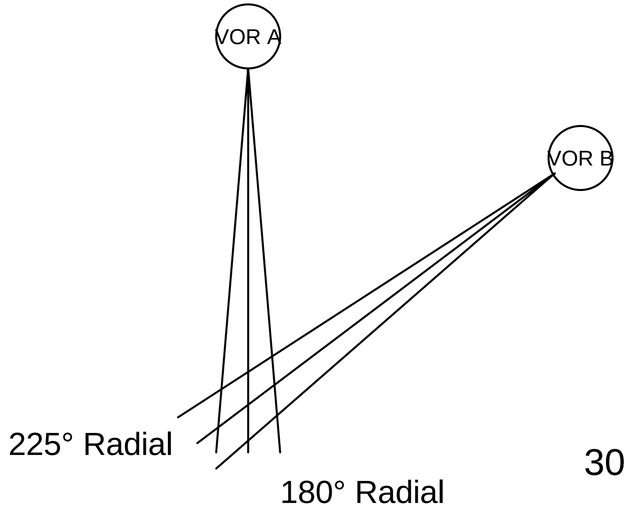


Notes: When tuning “side” radial, needle points to VOR before reaching radial (needle points away from VOR after passing radial)

Rho-Rho 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



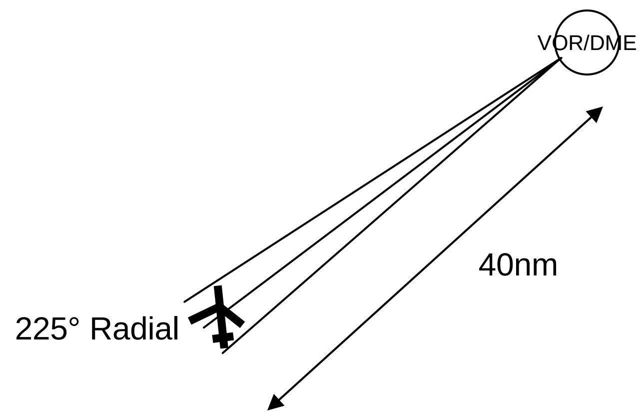


Distance Measuring Equipment (DME)

- DME provides aircraft distance to ground-station
  - Slant-range distance
- Interrogator on aircraft transmits pulsed interrogation signal
- Transponder on ground responds to interogator 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-sconds

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 iof 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 5th 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 earths rotation
- Drift
  - Any errors in accelerations amplified in velocities and position
  - Compensating for errors, leads to designs for < 0.8nm/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