SYST460/560

NAVIGATION

George Mason University

November 18th, 2013

Center for Air Transportation Systems Research (CATSR)

OBJECTIVES

By the end of this session, you will:

- Know terminology related to pilot aircraft navigation (Charts, Navigation icons, navigation equipment and techniques)
- Know underlying principles of navigation (true/magnetic, dead-reckoning, triangulation, wind correction angle…)
- Be able to perform manual navigation tasks (position fixing)

Class Overview

Basics - General Concepts (VFR vs. IFR, Airspace, Basic Nav. calculations)

Types of navigation

- Pilotage
- Dead-reckoning
- Radio Navigation

Flying the navigation

- Pre Flight preparation
- Corrections

Radio Navigation

- Non-directional Radio Beacon (NDB)
- Very High Frequency Omni-range Radio (VOR)
- Distance-Measuring Equipment (DME)

Inertial Navigation

- Inertial Navigation System (INS)

Satellite Navigation Systems

- Global Positioning System (GPS)

Overview - Radio Navigation

Non-directional Radio Beacon (NDB)

- "Here I am"
- Only at airports

Very High Frequency Omni-range Radio (VOR)

- "Here I am & this is the course from me to you"
- At airports and on routes between airports

Distance-Measuring Equipment (DME)

- "Here I am & this is the distance from me to you"
- At airports and on routes between airports

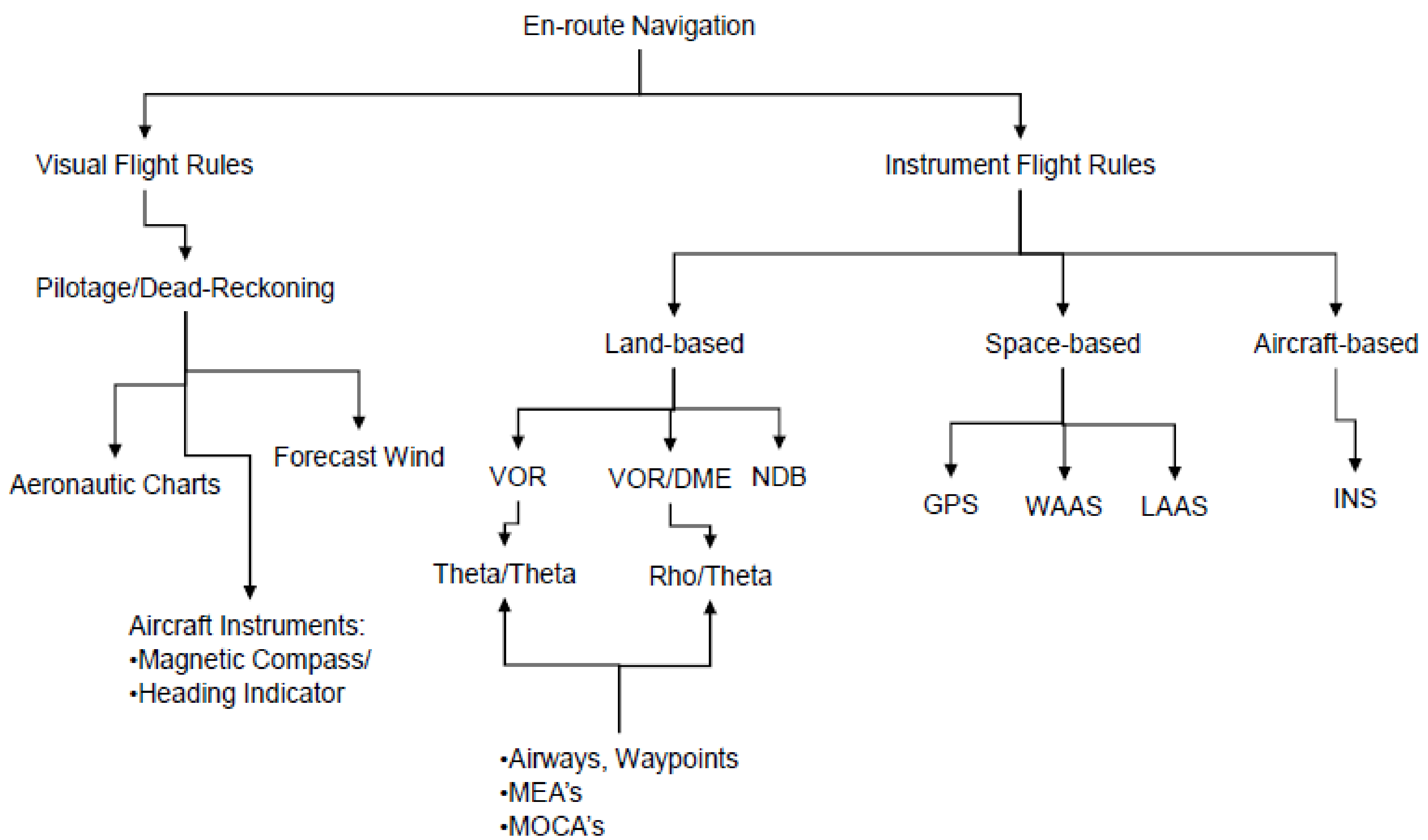
Inertial Navigation System (INS)

- "This is your latitude, longitude, groundpseed, …"
- Accelerometers exhibit drift over time

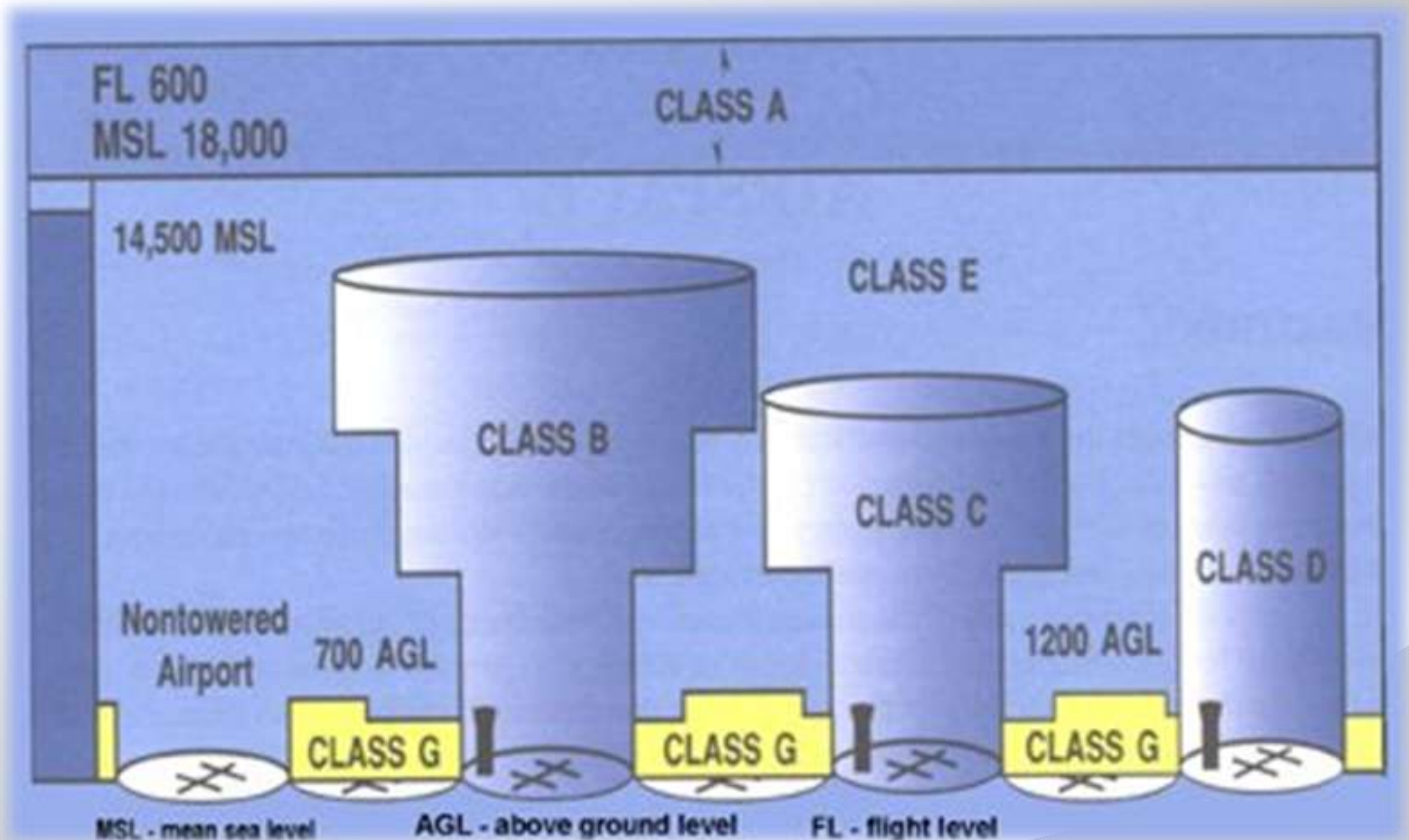
Global Positioning System (GPS)

- This is your latitude, longitude, groundspeed, …

Basics – Flight Rules



Basics-Airspaces



Basics-Charts

Sectional VFR Charts

http://quest.arc.nasa.gov/aero/virtual/demo/navigation/tutorial/tutorial8.html

Airports and Airports Data

http://quest.arc.nasa.gov/aero/virtual/demo/navigation/tutorial/tutorial8.html

- Listen to AWOS: Tune in, press three times

http://www.allweatherinc.com/aviation/awos_dom.html

- Morse Code:

http://www.glassgiant.com/geek/morse/

- Practice: Frankfort Airport – See Handout

http://vfrmap.com/?type=vfrc&lat=40.273&lon=-86.562&zoom=10

Basics-Direction

Definition:

- Course: Intended track
- Heading: A/C Fore-aft axis
- Track : Track made good

True vs. Magnetic North

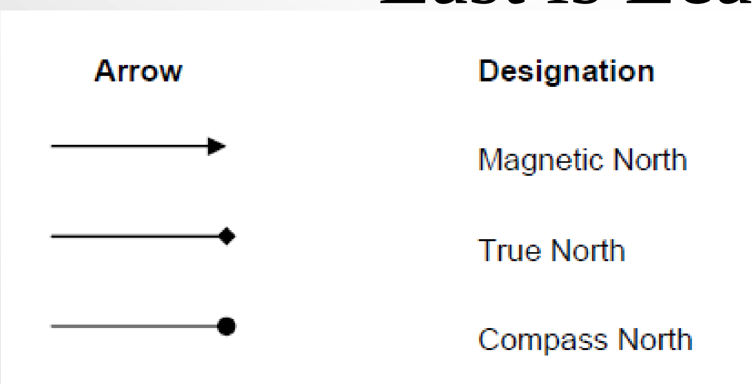
Direction (cont.)

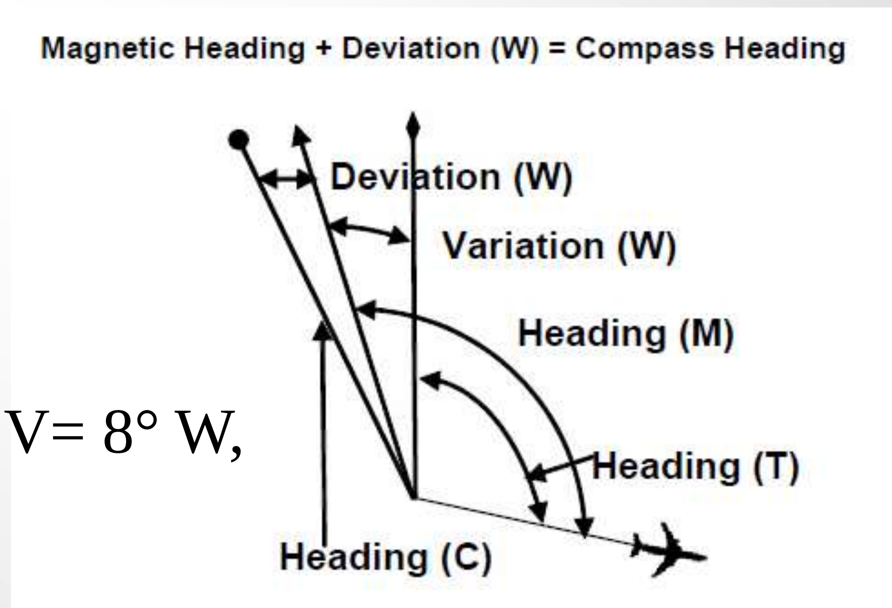
Variation (Isogonal lines)

Deviation (Aircraft Magnetism)

True to Magnetic to Compass

East is Least and West is Best

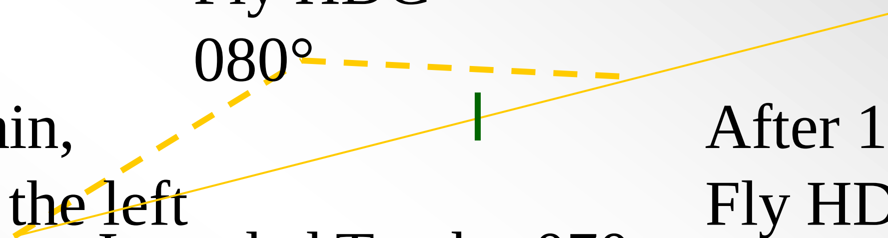




True Course 100°, V= 8° W,
D= 2°W
What is CH?

Wind Corrections

Less than ½ distance



Double Drift Correction Angle

More than ½ distance

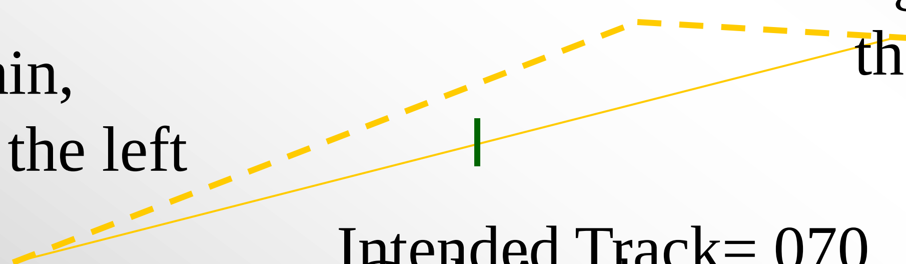


Figure out the angle to the other end and sum

4°+ 5°= 9°

➔ Fly HDG 079°

Practice HDG Correction

Intended track: 160°

Total leg time: 25 min

1st Checkpoint after 8 minutes, you are 7° Right (starboard)

Questions:

- What technique you need to use?
- What is your Corrected heading? Do you need to change it again before your arrival point? If yes, give new heading.

Types of Navigation

Pilotage

- Landmarks
- Beacons (Bonfires)

Dead-reckoning

- Planning
- Flying the navigation/ Adjustments

Radio Navigation:

- Ground based:
  - NDB
  - VOR
  - DME
- Aircraft Based: INS
- Satellite Based: GPS

Flight Preparation:

- METAR : Meteorological Aviation Reports

TYPE	ID	TIME	WIND	VIS	WX	SKY	T/TD	ALT	REMARK
METAR	KORD	041656Z	19020G26KT	6SM	-SHRA	BKN070	12/08	A3016	RMK AO2

  http://www.wunderground.com/metarFAQ.asp#rmk

- TAF: Terminal Weather Forecast
- Winds Aloft:

http://aviationweather.gov/adds/winds/

- NOTAMS: Note to Airman

https://pilotweb.nas.faa.gov/PilotWeb/

Navigation Log

Check points

Find/Decide: Course, Altitude, Wind/Temp, CAS, Leg

Work out: TAS,TC, TH, MH,CH, GS, ETE, ETA, Fuel

$$TAS = CAS + ((2 \times {}^{CAS}/_{100}) \times \text{Altitude in 1000s of ft})$$

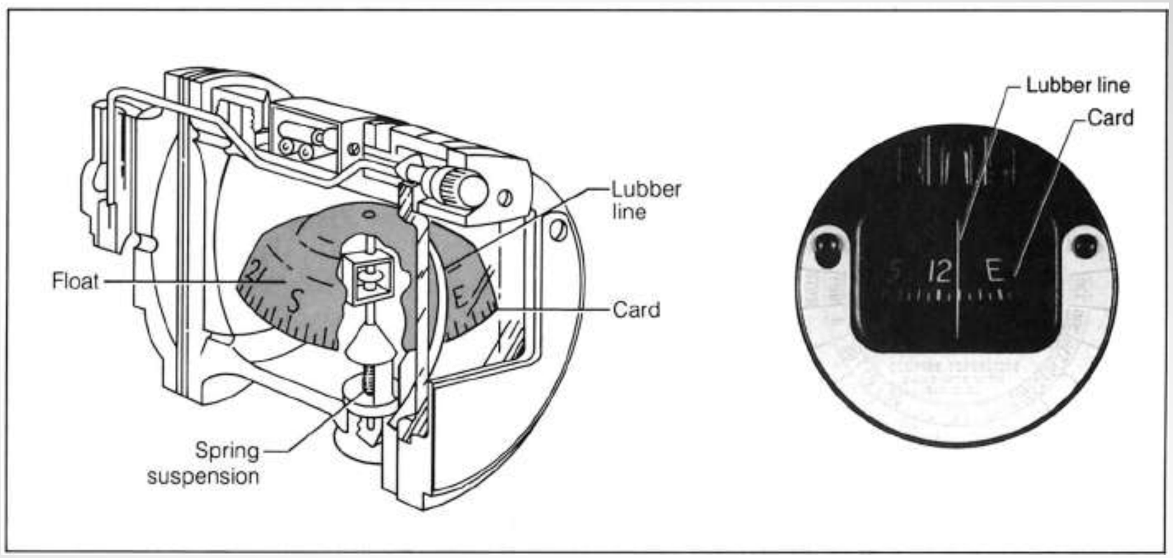
Check Points (Fixes)	VOR	Course (Route)	Altitude	Wind		CAS	TC	TH	MH	CH	Dist	GS	Time Off		Gallons
	Ident			Dir.	Vel.						Leg	Est.			
	Freq.			Temp.		TAS	-L +R WCA	-E +W Var.	±Dev.		Rem	Act.	ETE	ETA	Burned
													ATE	ATA	Rem.

More on NAV Log:

http://www.hsu.edu/uploadedFiles/about/academic_divisions/School_of_Business/Aviation_Dept/Aviation_Support_Documents/Flight_Planning/VFR%20Flight%20Planning%20Notes%20-ver%204.pdf

Aircraft Instrument -Magnetic Compass

- General: freely suspended magnet



- Errors:
  - Acceleration
  - Turing

Aircraft Instruments –Heading Indicator

Heading indicator uses spinning gyroscope

Initialized prior to takeoff using compass rose

Includes a TO or FROM indication

Subject to drift, must be reset during flight (S&L)

Possible inaccuracies:

- Initialization errors
- Internal bearing friction (Real wander)
- Drift (transport wander)
- Mechanical failures (dust, moisture, joints…)

Radio 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

NDB Navigation

Relative Bearing Indicator (Clockwise)

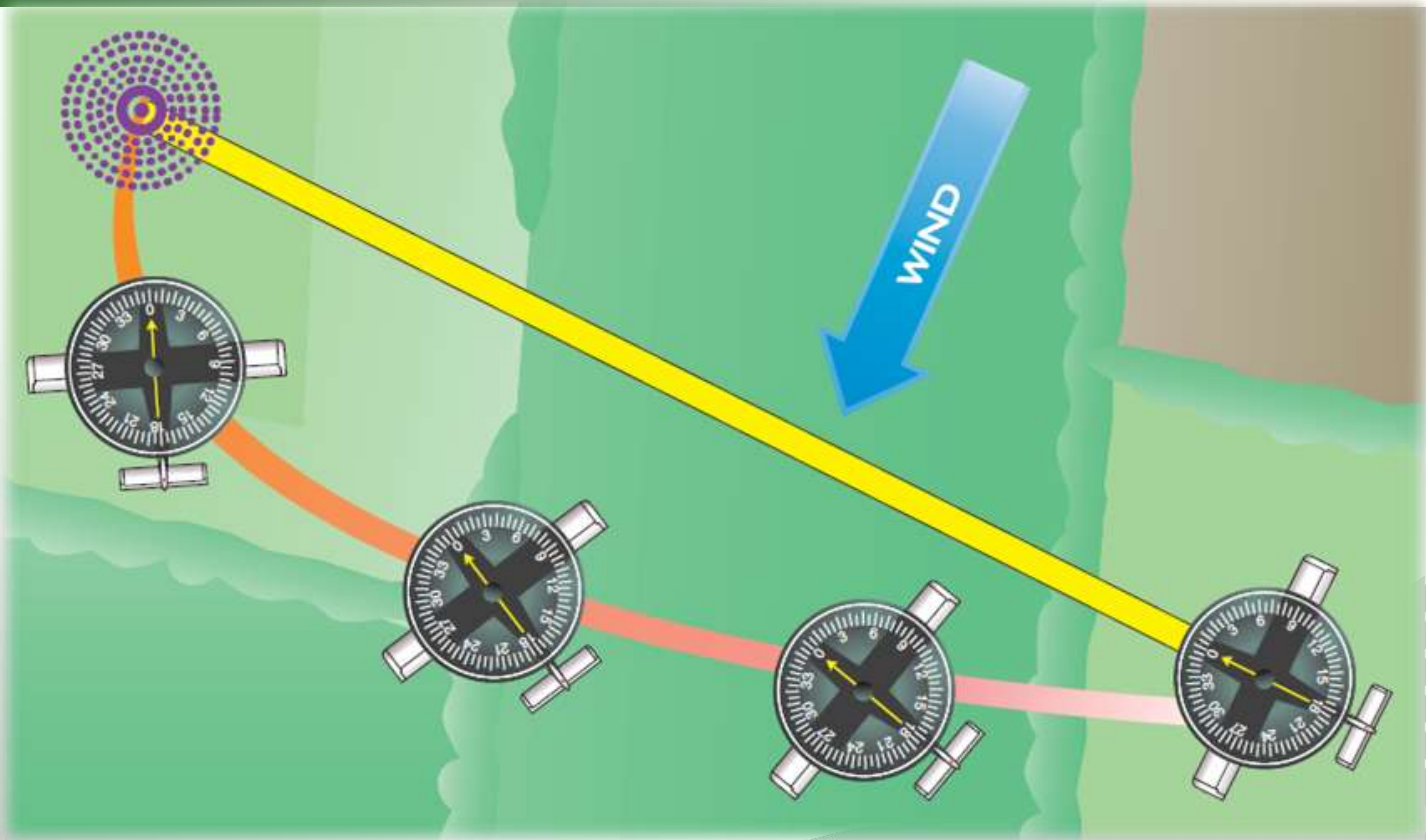
Relative Bearing to the station 340

Note: A/C not necessarily heading N

- Heading 015
- QDM= 340 + 015 = 355
- QDR = 175 (Reciprocal)

Homing

NDB Navigation- Homing



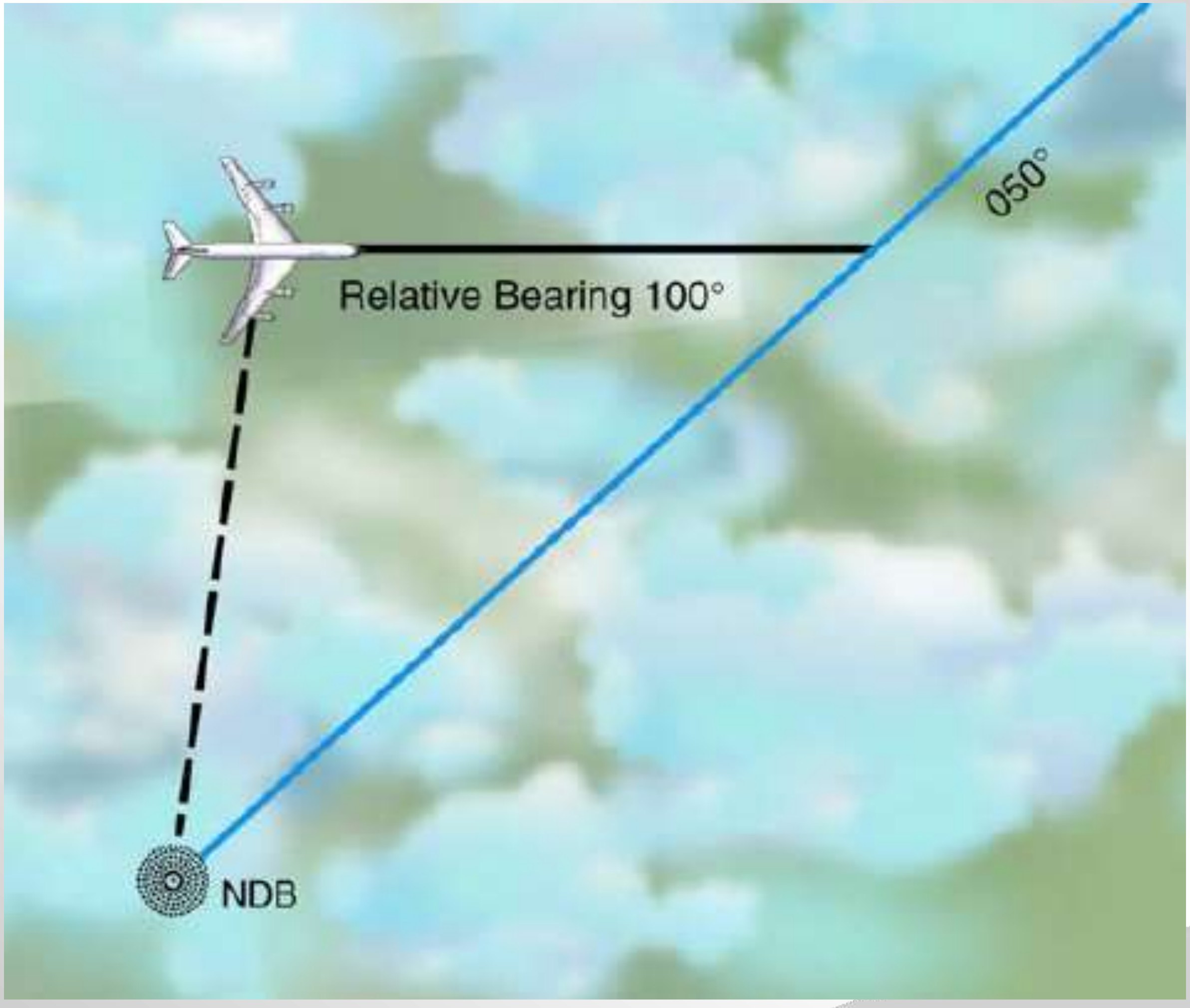
NDB LOP

Magnetic Heading 090

Relative Bearing 100

Where is the NDB Station?

NDB Interception- Outbound

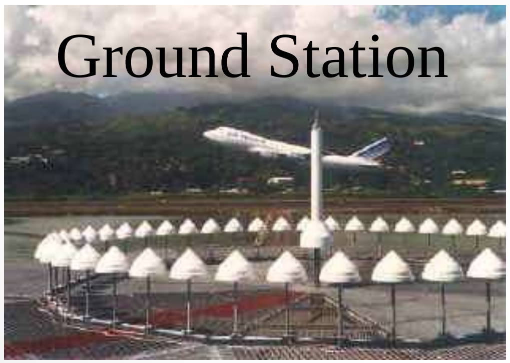


Heading east
Turn left when RBI shows 140

VOR

Very High Frequency Omnidirectional Radio Range

Ground Station



Aerial in small aircraft

HSI

Display

Navigation Display

VOR- Operation

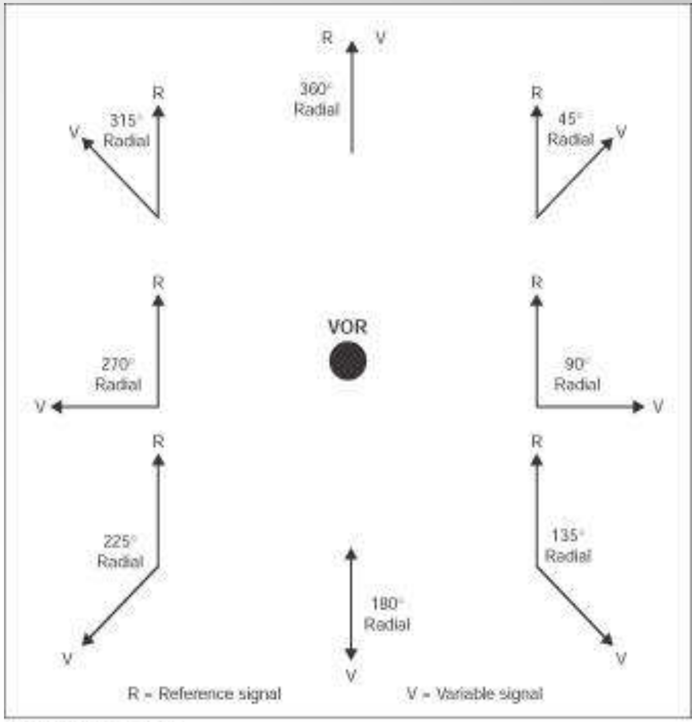
VOR emits two modulations, A/C eq. senses the phase.

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 Volume

High-altitude VORs

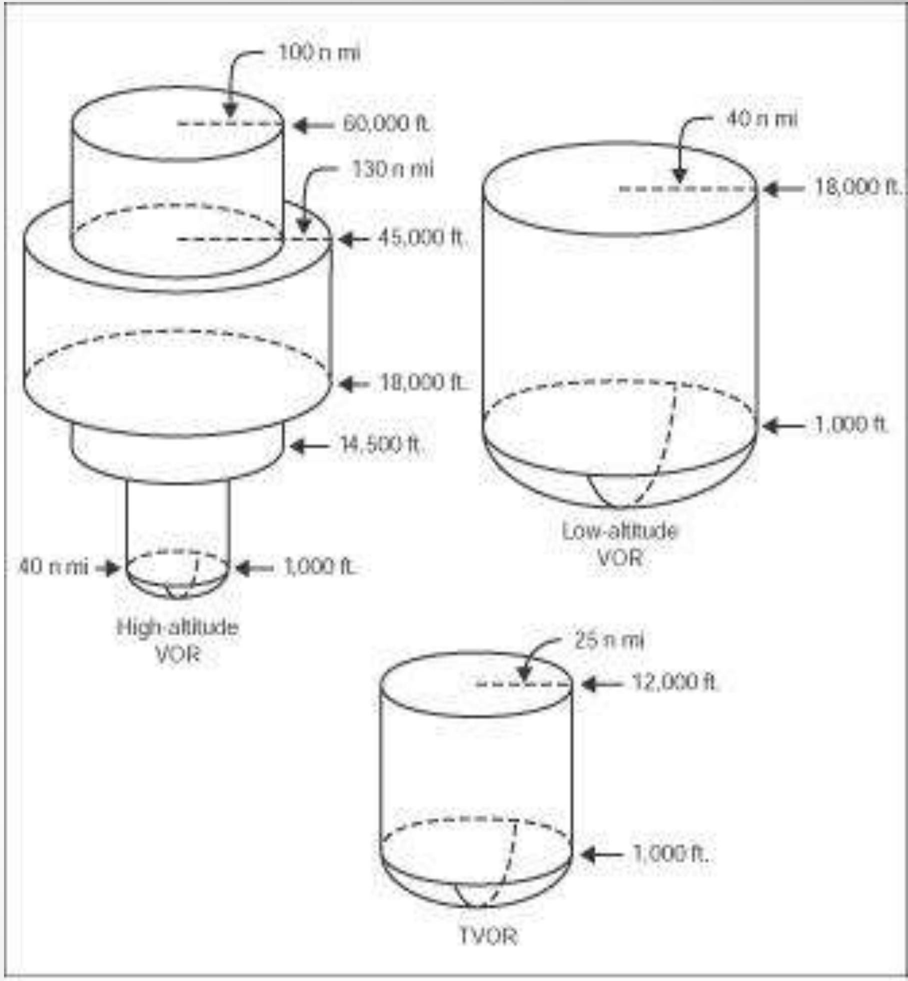
- Frequency 112.00 to 117.90 mHz
- 200 nautical mile range, between 18,000 and 60,000 feet

Low-altitude VORs

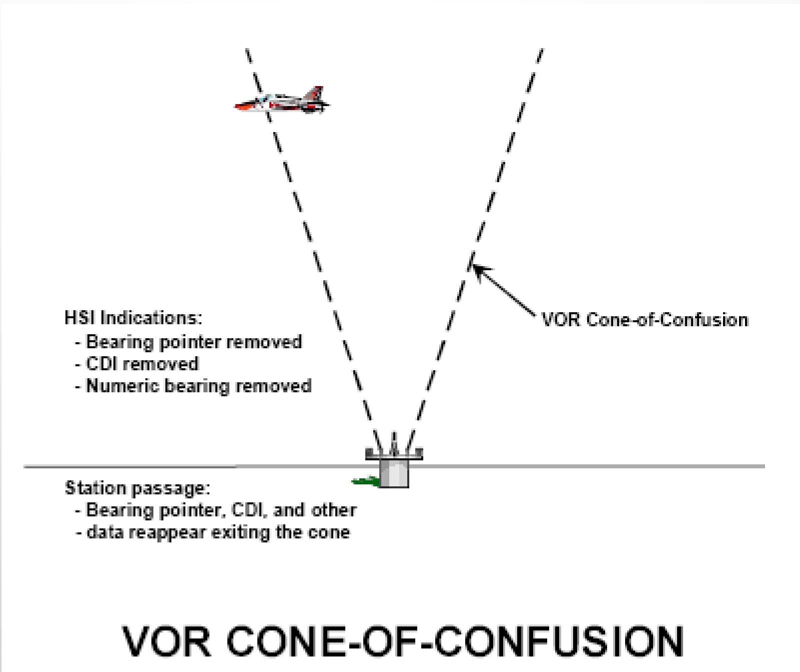
- Frequency 108.10 to 111.80
- 40 nautical mile range, below 18,000 feet

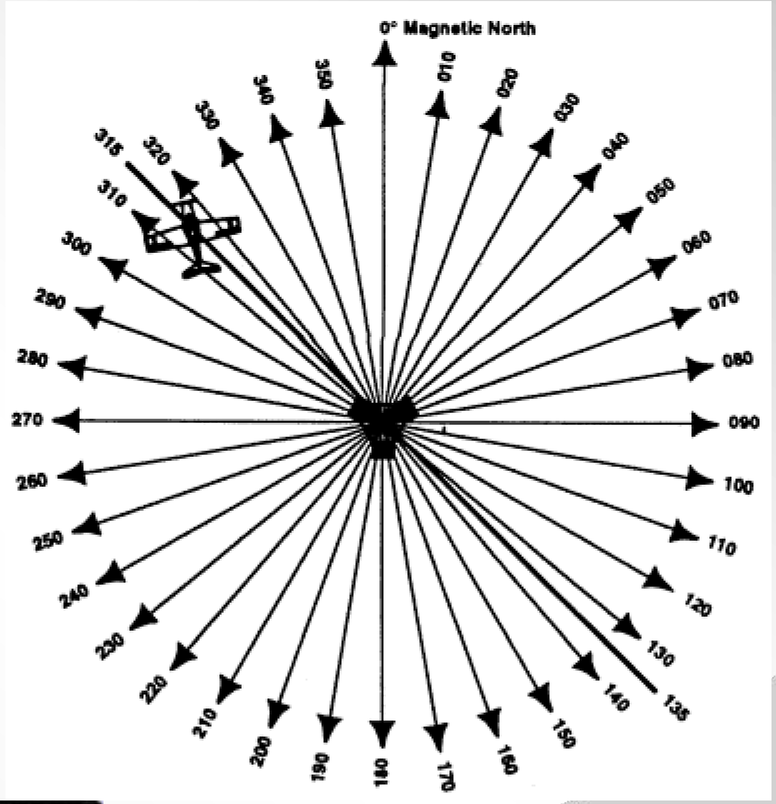
Terminal VORs (TVOR)

- 2.5 nautical mile range



Cone of Confusion





VOR Navigation

Using VOR in Cockpit : SID

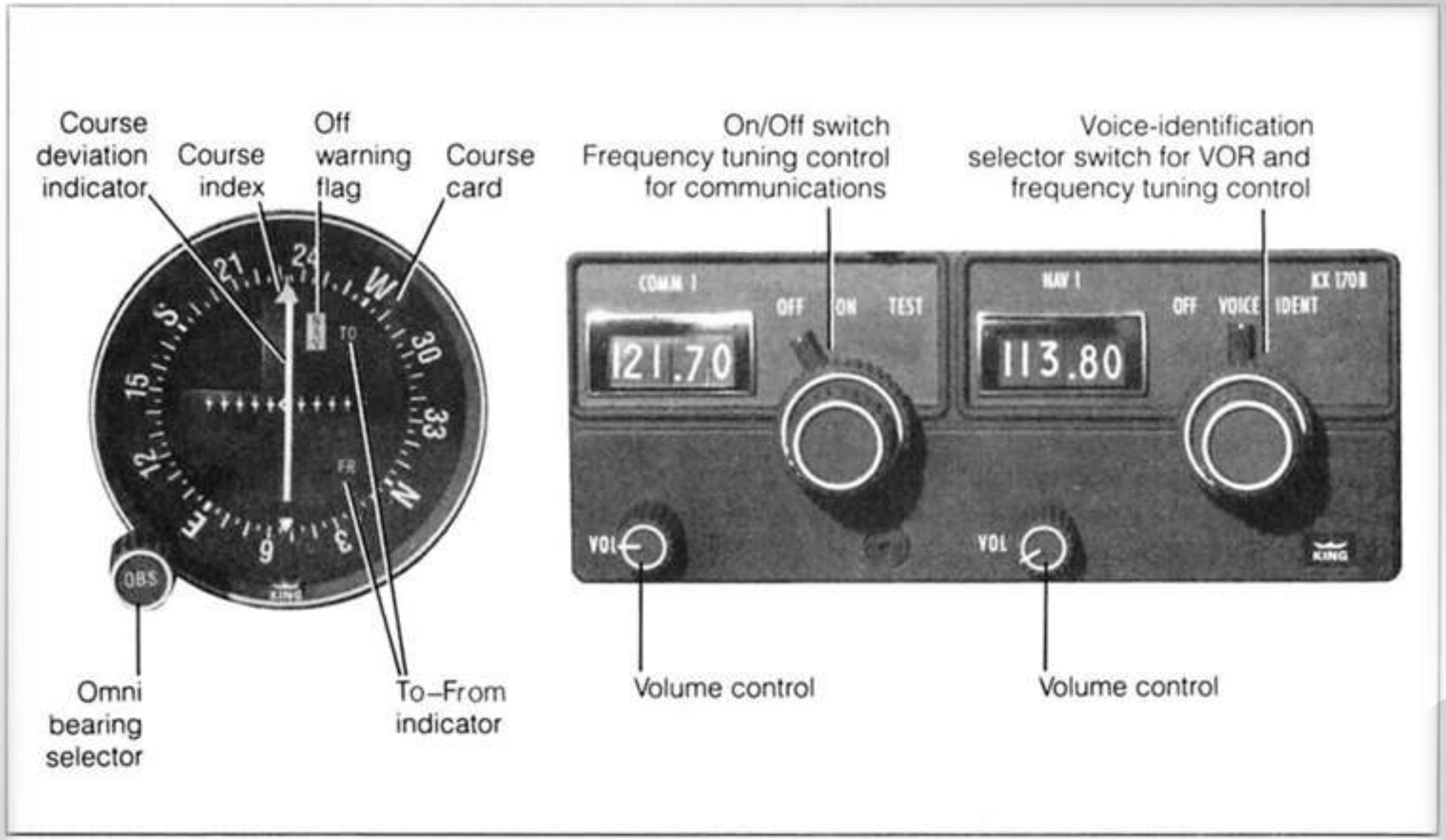
S- Select: Dial in VOR frequency

I- Identify: Check Morse Code

D- Display:

- Check for flags,
- 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*

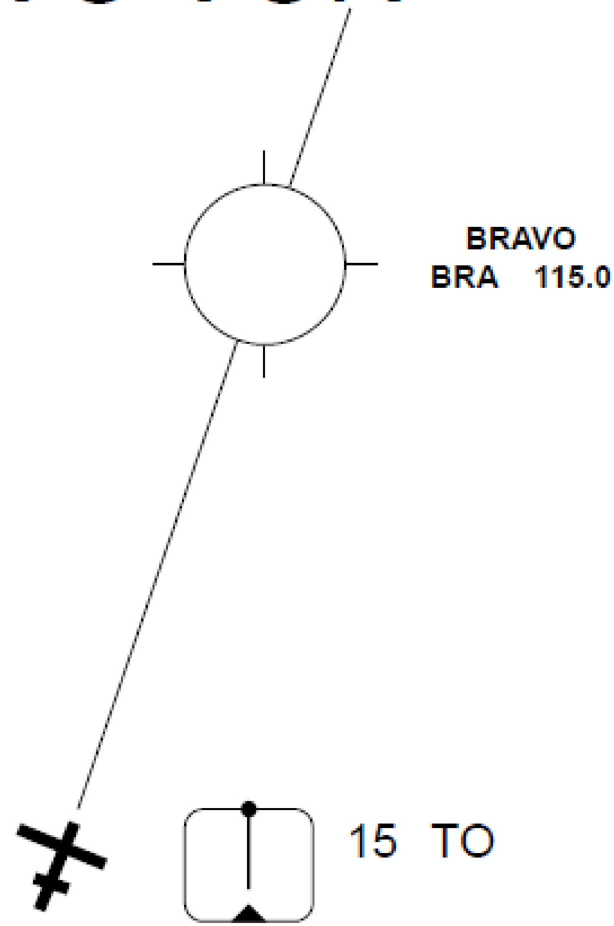
Display



Course deviation indicator
Course index
Off warning flag
Course card
On/Off switch
Frequency tuning control for communications
Voice-identification selector switch for VOR and frequency tuning control
COMM 1
OFF
ON
TEST
121.70
NAV 1
KX 170B
OFF
VOICE
IDENT
113.80
VOL
VOL
OBS
TO
FR
Omni bearing selector
To–From indicator
Volume control
Volume control

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



VOR Navigation- HSI

Example with

Heading

Required QDR/QDM

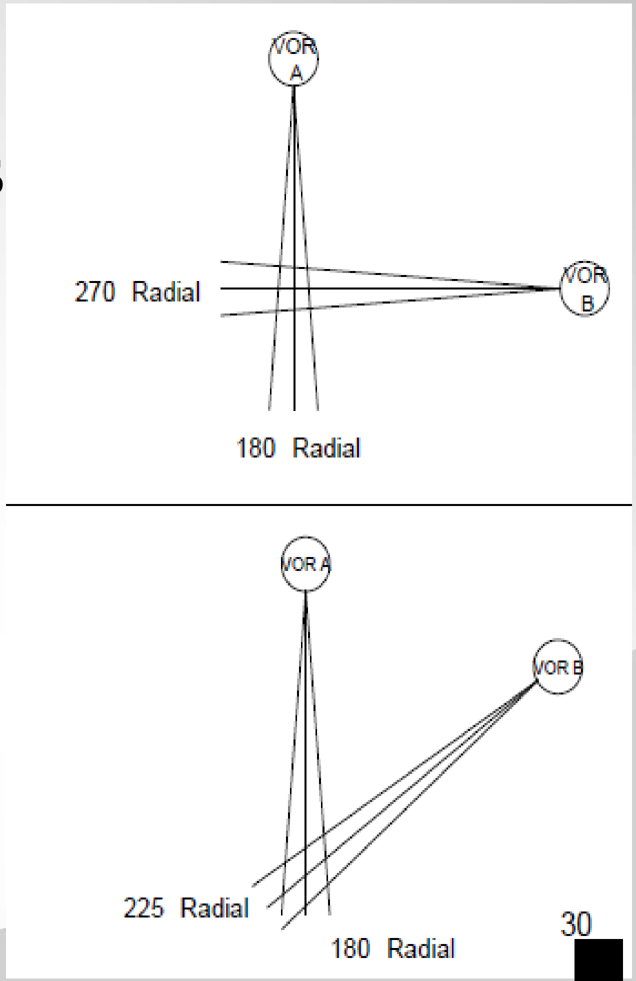
VORs Errors

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

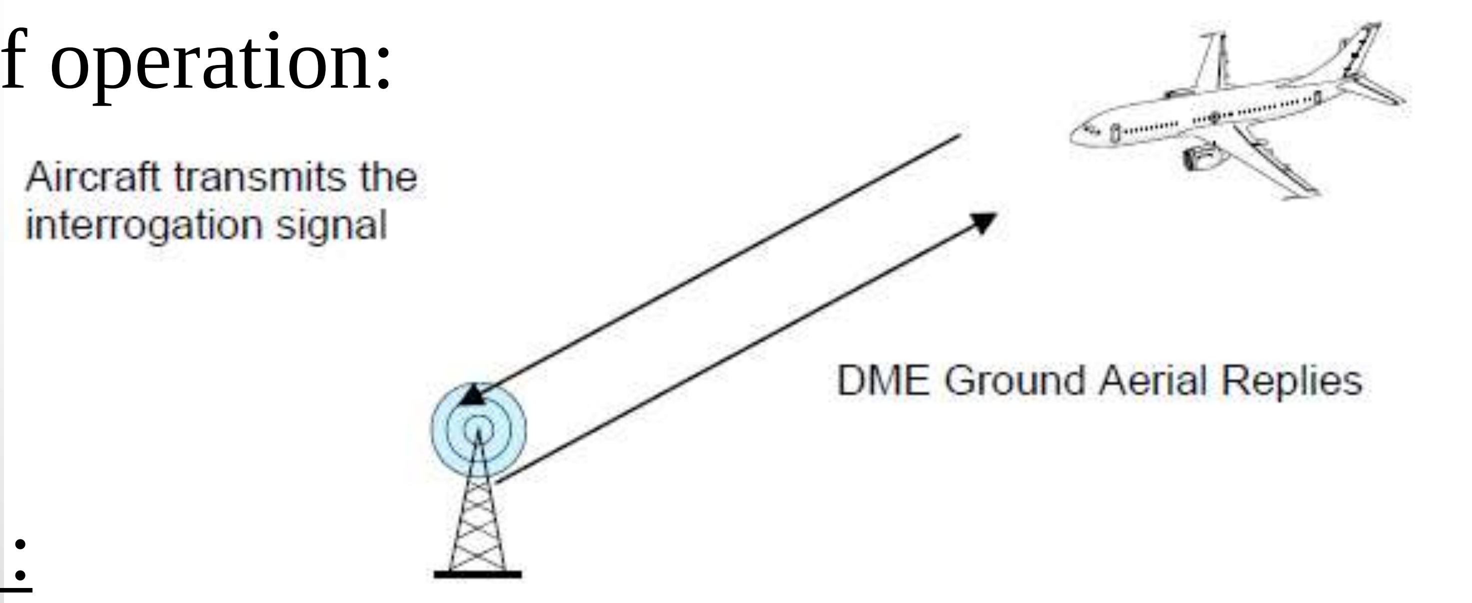


Distance Measuring Equipment - DME

Provides Pilot with Slant Distance

Coupled with VOR

Principle of operation:

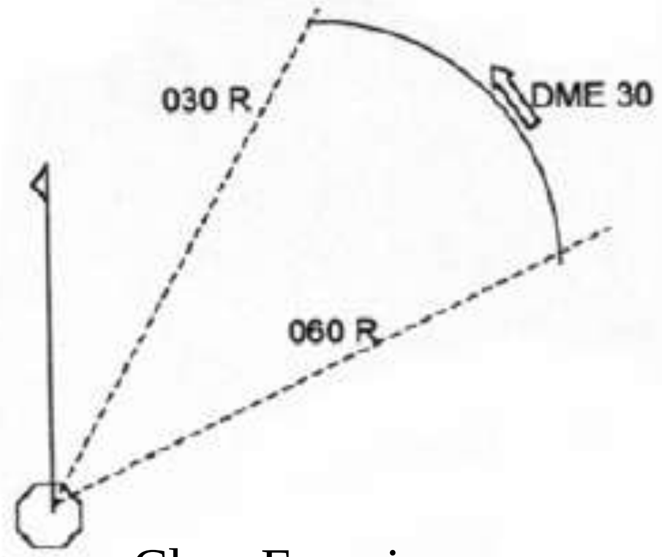


Frequency :

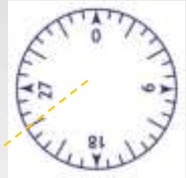
- ✓ Airborne interrogator : 1025 Mhz – 1150 Mhz
- ✓ Ground based transponder : 962- 1024 and 1051 – 1213 Mhz

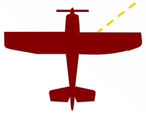
DME Uses

Flying the Arc:



- Position Fixing





Radial 240, 20 nm

Class Exercise:

An aircraft flying at 45 000 ft with an indicated DME of 175 nm. What is the true range?

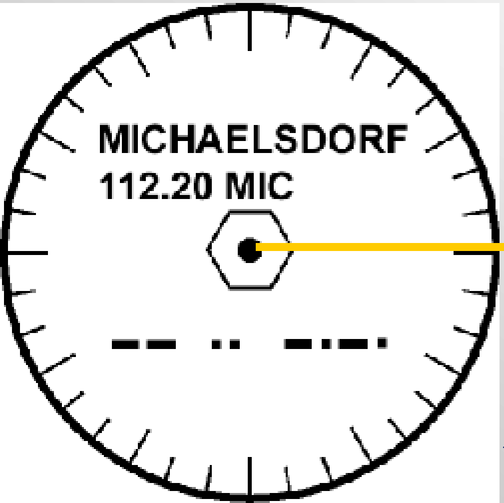
An aircraft overflying a DME at 40 000ft. What is the DME reading?

Position Fixing

VOR Radials: Theta/Theta

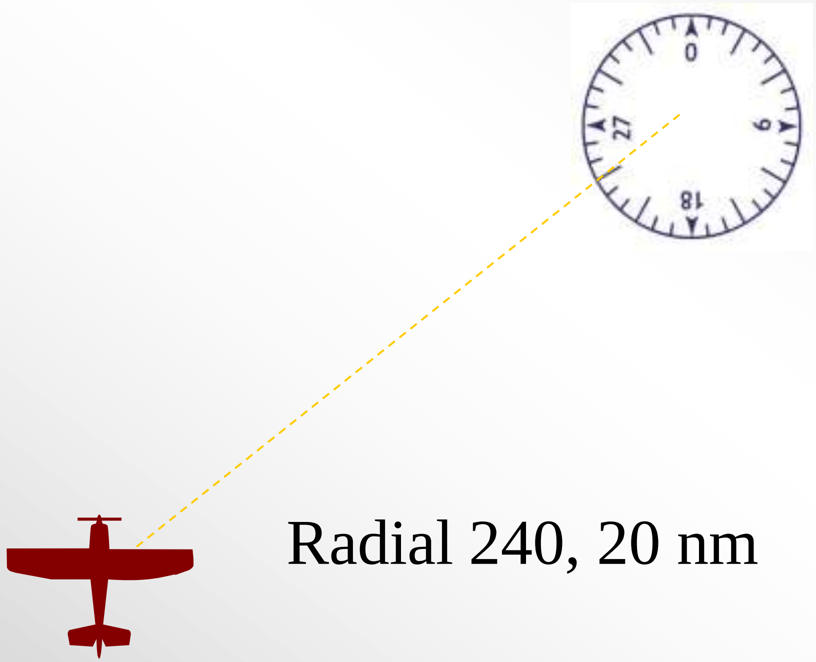
Radials from 195 ADB VOR

and 090 from MIC VOR



Position Fix

Theta/Rho



Radial 240, 20 nm

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

Segments

Satellite Segment (the constellation):

- 6 orbits inclined by 60 deg
- 4 satellites per orbit
- Total 24 (3 functional spares)

Control Segment

User Segment

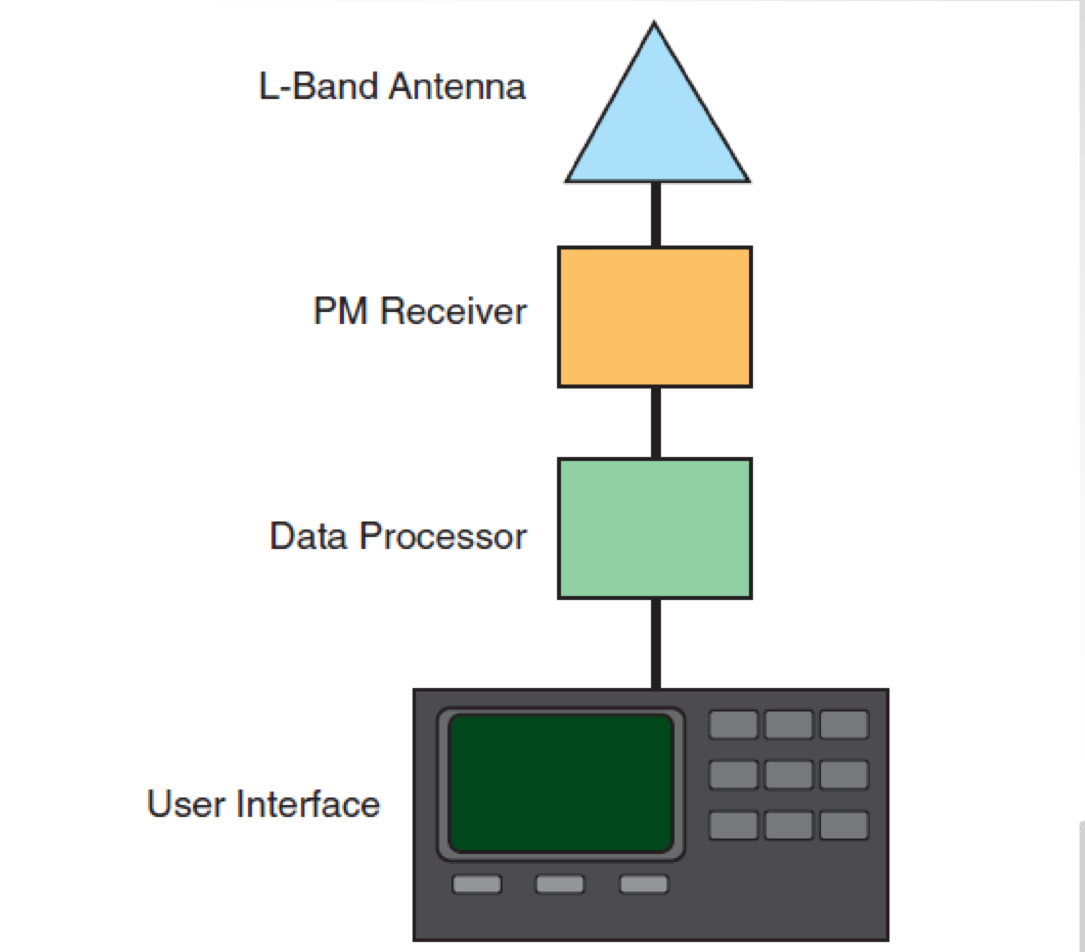
Control Segment

THE CONTROL SEGMENT

This provides the control and support system for GPSI and consists of:

Master Control Station (MCS)	Colorado Springs
Monitoring Stations (MS)	Ascension
	Hawaii
	Kwajalein
	Diego Garcia
Back up MCS	Onizuka

User Segment



Operation

PRN: Pseudo random noise from satellite

- Coarse Acquisition (C/A) Signal
- Navigation message (including euphemeris, time)
- Precision (P) message

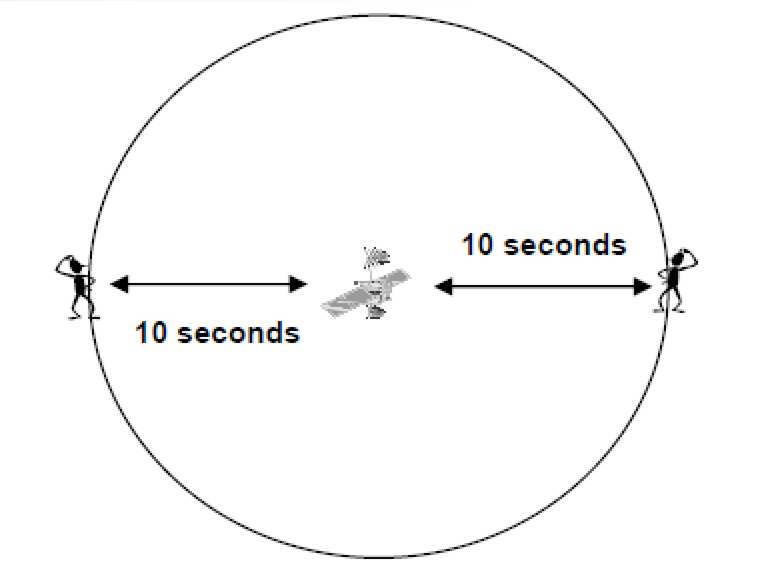
Receiver : Receives C/A signal ➔ TOA➔ Pseudo range

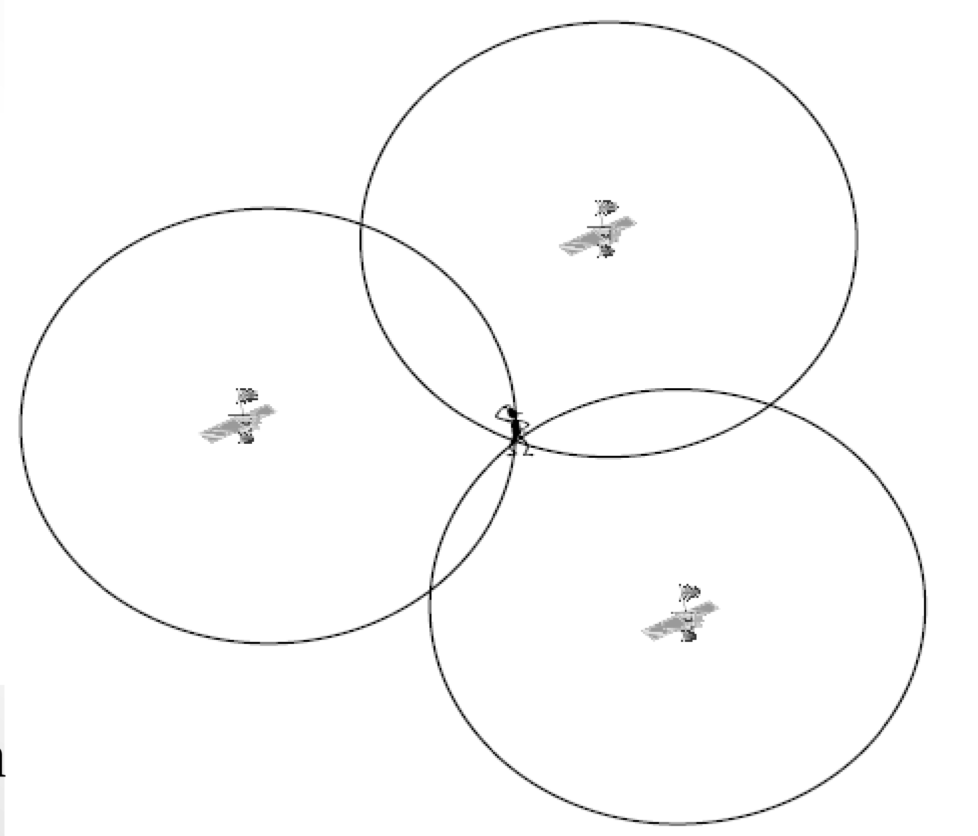
- Pseudo Range (satellite clock error, atmospheric distortion…)
- Collected from Navigation Message

Pseudo Range corrected for Satellite Clock bias

➔ Accurate Range

Position





Note: Time information derived using a 4th satellite.

GPS Accuracy

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

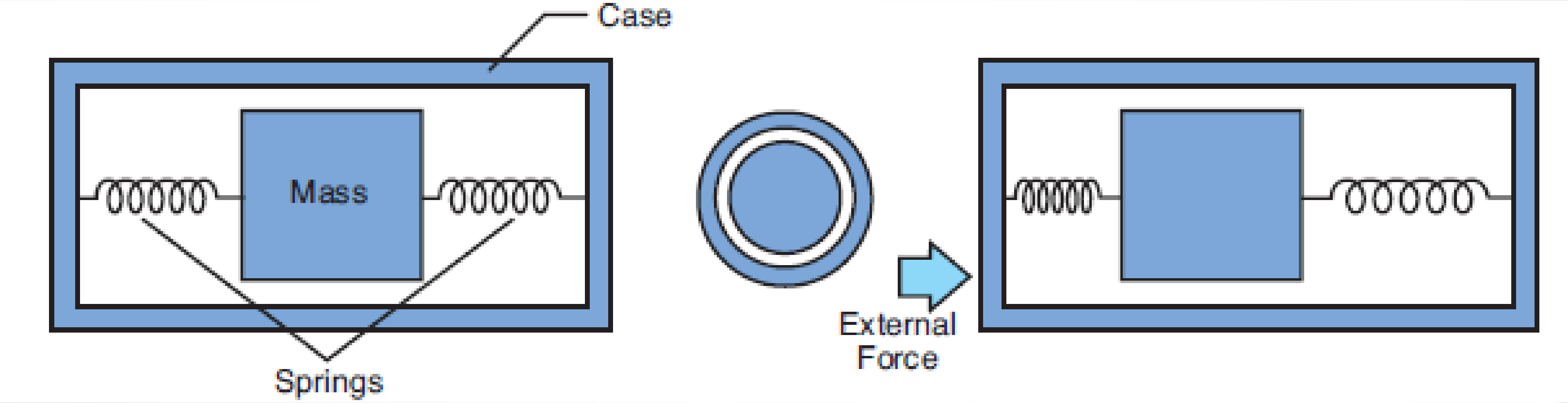
Inertial Navigation System

- 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

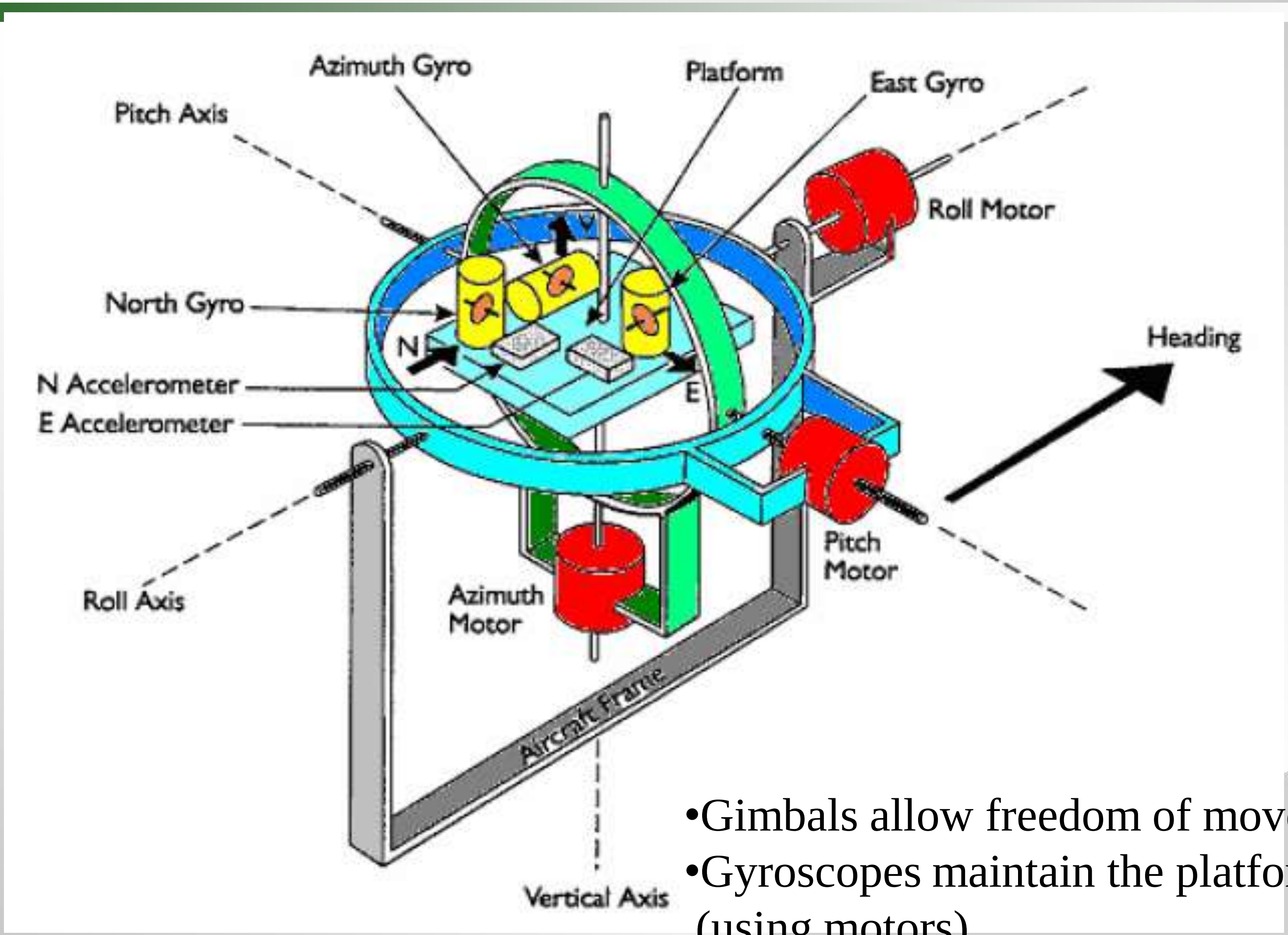
- Measures accelerations in 3-D space
  - Integrate accelerations to get velocities
  - Integrate velocities to get position
- INS records movement relative to Celestial Sphere (not Earth)
  - Mount INS and turn on.
  - Hour later, INS has not moved, accelerometers have detected earths rotation
- Drift
  - 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

Use of Inertia



F= m*a
To get v ➔ integrate a
To get x ➔ integrate v

INS – Inertial Navigation System



- Gimbals allow freedom of movement
- Gyroscopes maintain the platform level (using motors)
- Accelerometers detect accurate acceleration

It is the End of the Session

You should:

- Know terminology related to pilot aircraft navigation (Charts, Navigation icons, navigation equipment and techniques…)
- Know underlying principles of navigation (true/magnetic, pilotage/dead-reckoning, triangulation)
- Be able to perform manual navigation tasks (position fixing)

If any of the above is not clear: hkourdal@gmu.edu