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, groundspeed, …”
- Accelerometers exhibit drift over time

Global Positioning System (GPS)
- This is your latitude, longitude, groundspeed, …
Basics – Flight Rules

En-route Navigation

- Visual Flight Rules
  - Pilotage/Dead-Reckoning
    - Aeronautic Charts
      - Aircraft Instruments: Magnetic Compass/Heading Indicator
    - Forecast Wind
- Instrument Flight Rules
  - Land-based
    - VOR
  - VOR/DME
  - NDB
  - Rho/Theta
    - Airways, Waypoints
    - MEA's
    - MOCA's
  - Space-based
    - GPS
    - WAAS
    - LAAS
  - Aircraft-based
    - INS
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 (Isogononal 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
Fly HDG 080°
After 10 min,
Drift 5° to the left
Intended Track = 070

Double Drift Correction Angle
More than ½ distance
After 20 min,
Drift 2° to the left
Intended Track = 070
Crab Angle

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

1\textsuperscript{st} 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

  ![METAR example](http://www.wunderground.com/metarFAQ.asp#rmk)

- **TAF**: Terminal Weather Forecast

- **Winds Aloft**:

  ![Winds Aloft example](http://aviationweather.gov/adds/winds/)

- **NOTAMS**: Note to Airman

  ![NOTAMS example](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

\[ \text{TAS} = \text{CAS} + \left( \frac{2 \times \text{CAS}}{100} \right) \times \text{Altitude in 1000s of ft} \]

More on NAV Log:
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…)

![Heading Indicator Image]
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

HSI Indications:
- Bearing pointer removed
- CDI removed
- Numeric bearing removed

Station passage:
- Bearing pointer, CDI, and other
- data reappear exiting the cone

VOR 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
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

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 40 000 ft. What is the DME reading?

Radial 240, 20 nm
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)
Monitoring Stations (MS)

Colorado Springs
Ascension
Hawaii
Kwajalein
Diego Garcia
Onizuka

Back up MCS
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 $\Rightarrow$ TOA $\Rightarrow$ Pseudo range
  • Pseudo Range (satellite clock error, atmospheric distortion…)
  • Collected from Navigation Message
Pseudo Range corrected for Satellite Clock bias $\Rightarrow$ 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 $< 0.8\text{nm/hr}$
- Schuler Drift
  - 84 minute periodic error (period of pendulum length of diameter of Earth)
  - Over long time, error nulls itself
Use of Inertia

\[ F = m \cdot a \]

To get \( v \) \( \Rightarrow \) integrate \( a \)

To get \( x \) \( \Rightarrow \) 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