Outline

- Pilotage (look out the window)
- NDBs monitored via ADF (needle points to radio station)
- VOR (1950s upgrade to NDB)
- GPS and moving map
Section A

PILOTAGE AND DEAD RECKONING

Pilotage

- Navigation using visual landmarks
- VFR charts emphasize objects easy to identify from the air, e.g., highways, towns, big towers
- Ground procedure:
  - Plot planned course (avoid restricted areas, open water)
  - Select checkpoints along the route
  - Measure distance from checkpoint to checkpoint
  - Develop flight plan and navlog
- In-flight procedure
  - Fly planned headings and airspeed
  - At each checkpoint, use left/right deviation for wind correction
Example

- From: Hanscom Field, Bedford, MA (BED)
- To: Morse State Apt., Bennington, VT (DDH)

Planning Goal: Navlog

<table>
<thead>
<tr>
<th>Waypoints</th>
<th>MEA / MORA Freq</th>
<th>Route</th>
<th>MC</th>
<th>Fuel (gal)</th>
<th>Dist (NM)</th>
<th>GS (Kts)</th>
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</table>
Dead Reckoning

• Navigation solely by means of computations based on time, airspeed, distance and direction
• Use in conjunction with pilotage
• Steps:
  – Plot course on chart, including landmarks
  – Measure true course (TC) at meridian nearest the center of the course
  – Correct for forecast wind to find true heading (TH)
  – Correct for magnetic variation to find MH
  – Estimate ground speed and ETE for each leg (account for time, speed, distance to climb in the POH)

Courses and Headings

• Course
  – Direction over the ground
• Heading
  – Direction aircraft is pointing
  – Wind can make heading different from course
• True (course or heading)
  – Referenced to true north pole
• Magnetic (course or heading)
  – Referenced to magnetic north pole
Courses and Headings

- **True Course**
  - Direction of line from A to B relative to true north
- **True Heading**
  - Direction airplane is pointed, given wind corrections, relative to true north
- **Magnetic Course**
  - Direction of line from A to B relative to magnetic north
- **Magnetic Heading**
  - Direction airplane is pointed, given wind corrections, relative to magnetic north
- **Compass Heading**
  - Magnetic Heading corrected for airplane-specific compass errors

Magnetic Variation

- **Isogonic Line**: correction factor to convert from True to Magnetic
  - east is least, west is best (subtract east, add west)
Local Magnetic Variation

- True north != magnetic north
- VORs in magnetic
- Isogonic lines
- “east is least; west is best”: true + W variation = mag

Magnetic Deviation

- Magnetic and electrical fields inside the cockpit disturb compass
- Compass Correction Card
  - Magnetic heading -> Compass heading
  - Specific to each airframe (not just aircraft type)
  - Must be updated periodically

Worthless if heated windshield is turned on!
Plotter and E6B Introduction

• **Plotter**
  - Flight planning tool to measure distances and courses
    - Sectional: 1 inch -> 6.86nm / 7.89sm
    - TAC: 1 inch -> 3.43nm / 3.95sm
    - World Aeronautical Chart (WAC): 1 inch -> 13.7nm / 16sm

• **E6B**
  - Evolved to make common calculations easier (slide rule)
  - Two sides: computer side and wind side
  - Waterproof and no batteries required

Using the Plotter

• Used to determine true course between two waypoints
• Different distance scales
• Key points:
  - Use correct distance scale for chart type in use
  - Use Meridians (North-South Lines) for course calculations
Using the Plotter

- True Course (TC): 038° NORTH
Using the E6B: Computer Side

- Calculator is a simple way to calculate ratios between values
- Sliding inner ring normally represents TIME
- Outer ring normally represents VALUE of interest
  - Fuel per unit time
  - Distance per unit time

At 90 Knots...
10 minutes (inner ring) to fly 15nm (outer ring)
Using the E6B: Wind Side

• Used to find impact of wind
  – Wind correction angles
  – Groundspeed
• Given partial information, useful for determining other missing information
  1. True airspeed
  2. Groundspeed
  3. Wind correction angle
  4. Wind speed
  5. Wind direction

Wind Direction: 210°
Wind Speed: 20 knots
True Course: 180°
True Airspeed: 147 knots
Using the E6B: Wind Side

Wind Direction: 210°
Wind Speed: 20 knots
True Course: 180°
True Airspeed: 147 knots
Using the E6B: Wind Side

Wind Direction: 210°
Wind Speed: 20 knots
True Course: 180°
True Airspeed: 147 knots
Groundspeed: 129 knots
Wind Correction Angle: 4°

Navigation Log Form

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<th>Time</th>
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<th>True Course</th>
<th>True Airspeed</th>
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Private Pilot Ground School 23

Private Pilot Ground School 24

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Private Pilot Ground School 23

Private Pilot Ground School 24
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<th>Route</th>
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### SkyVector.com: free and easy

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Pilotage Summary

- Use winds aloft forecast to create a plan
- Correct heading based on passing over/ left/right of previously selected landmarks
- Fun skill, relationship to safety is unclear (Student pilot versus Commercial pilot)
- Still worth doing, but generate the navlog electronically!
- Knowledge Test: Built-in electronic E6B; plotter useful.

Section B

ADF NAVIGATION
This won’t be on the test…

... still fun to learn about.

Non-directional beacons (NDBs) set up in the 1930s.

Pilot originally had to turn dial to hunt for station direction.

The Automatic Direction Finder (ADF) was a huge innovation.

At right: from Flying 1952.

---

Automatic Direction Finder

- Automatic Direction Finder (ADF) – Unit in the aircraft
- Non Directional Beacon (NDB) – Ground Station
- Indicator – Compass rose with needle, needle points to the station
How to use the ADF

- Homing – Keep the needle pointed forward, airplane tracks curved path in wind
- Tracking – Needle offset due to wind, airplane tracks straight path over ground

Finding Magnetic Bearing

- Relative Bearing
  - Number read on face of the ADF
- Magnetic Heading
  - Number read from face of directional gyroscope
- Magnetic Bearing
  - Magnetic heading TO the station

Magnetic Heading + Relative Bearing = Magnetic Bearing
Movable Card ADF

- Turn card to match heading of aircraft
- Read magnetic bearing under needle

Figure 30. ADF (movable card).
Source: Public Domain

Section C

VOR NAVIGATION
VHF Omni-Directional Range (VOR)

- 1950s improvement to NDBs
- With no reference to a magnetic compass, receiver can determine the magnetic radial from station
- 360 radials (one for each degree)
- Can track “TO” or “FROM” station on a specific radial
- Can determine lat-long position by intersecting radials from two VORs

Three types of VORs

- VOR
  - Only transmits azimuth information
- VOR-DME
  - Distance Measuring Equipment (DME)
  - Azimuth plus distance from VOR information
- VORTAC
  - Military: Tactical Air Navigation (TACAN)
  - Azimuth plus distance navigation
  - Private Pilot Standpoint: Same Function as VOR/DME

Source: Public Domain
VOR Service Volumes

16.687

- **High-Altitude**
  - 100 NM
  - 130 NM
  - 18,000 ft.
  - 40,000 ft.
  - 40,000 ft.
  - 16,000 ft.
  - 14,000 ft.
  - 1,000 ft.
  - 40 NM

- **Low-Altitude**
  - 40 NM
  - 18,000 ft.
  - 1,000 ft.
  - 1,000 ft.

- **Terminal**
  - 25 NM
  - 18,000 ft.

**NOTE:** All elevations shown are with respect to the station’s site elevation (AGL). Coverage is not available in a cone of airspace directly above the facility.

Source: Public Domain

Parts of the VOR

- **Transmitter**
- **Receiver**
- **Indicator**
  - OBS – Omni Bearing Selector
  - CDI – Course Deviation Indicator
  - TO/FROM Flag

Source: Public Domain
VOT: test on the ground

- At Hanscom: tune 110.0
- "Cessna 182": indication should be "180 TO"
- VOR Test Facility (VOT) frequencies buried in the Chart Supplement

Using VORs

NOTE:
Easiest method to determine VOR deflection is to imagine the airplane is pointed in same direction as OBS

OBS reading is NOT sensitive to actual aircraft heading

Source: Public Domain
2. (Refer to Figure 20, area 3; and Figure 28.) The VOR is tuned to Elizabeth city VOR, and the aircraft is positioned over Shamboro. Which VOR indication is correct?

- A. 2.
- B. 8.
- C. 9.

Source: Public Domain
VOR simulators

- LuizMonteiro.com
  (Flash)
- List of apps: AOPA

Section D

GPS NAVIGATION
Global Positioning System (GPS)

- Broadcast time and position from multiple stations
- Each “time of flight” gives a position somewhere on a sphere
- Intersect 4 spheres to get an x,y,z location

Global Positioning System (GPS)

- Constellation of 32 satellites (2016); 31 in use
- Minimum of 5 observable from any point on earth
- 5 or more used for IFR operations
WAAS/SBAS

- Wide Area Augmentation System (WAAS): FAA-established ground stations that gather correction information
- Generic name: satellite-based augmentation system (SBAS)

From Wikipedia: WAAS uses a network of ground-based reference stations, in North America and Hawaii, to measure small variations in the GPS satellites’ signals in the western hemisphere. Measurements from the reference stations are routed to master stations, which queue the received Deviation Correction (DC) and send the correction messages to geostationary WAAS satellites in a timely manner (every 5 seconds or better). Those satellites broadcast the correction messages back to Earth, where WAAS-enabled GPS receivers use the corrections while computing their positions to improve accuracy.

A Garmin GTN 750

Combination of
- GPS
- NAV radio (VOR/ILS)
- COM radio
Garmin G1000 moving map

Avidyne PFD moving map
When operating VFR within 60 NM of Washington, DC (DCA VOR), must have taken special awareness training

Must have course certificate to show, but not onboard

91.25 - Aviation Safety Reporting Program

Reports submitted to the Aviation Safety Reporting Program will not be used in enforcement against a pilot

Exception: reports containing info about accidents or criminal offenses

Program intended to encourage reporting of situations hazardous to aviation safety

Subject to some important limitations, the FAA will actually waive fines or penalties for people who voluntarily report unintentional violations of the Federal Aviation Regulations through the program

Run by NASA: [http://asrs.arc.nasa.gov](http://asrs.arc.nasa.gov)
Summary

- Pilotage
- NDBs monitored via ADF
- VOR
- GPS and moving map

Captain Sully: ""If I'm ever unable to access [GPS] or use the compass..., I could just keep Venus in the left front corner of the windshield and we would reach California."

Alternative: call ATC with “Request vectors SFO.”