Student Study Notes – Canadian PPL
Aviation Ground School: Navigation

This version of my "Ground School: Navigation" study notes is from January 1st, 2017. I'll update this document any time I find the need to make any changes, and as I continue to progress through additional training.

I am sharing these study notes for anyone else who is taking their PPL in Canada. These aren't intended as a replacement for proper training. I'm only sharing these notes as a supplement covering many of the key points that I decided that I really needed to memorize while going through my own PPL studies. The info in these notes comes from a large number of different sources: The Transport Canada Flight Training Manual, Transport Canada's Aeronautical Information Manual (AIM), various flight schools and instructors (in multiple provinces), and numerous other books and online sources. These notes are not always in any particular order, although I tried to keep similar topics together in many cases.

Please note that while I have made every effort to ensure that all of the information in these notes is accurate, based on the sources from which I learned, you should verify everything here against what you've learned in your own study programs. I (Jonathan Clark) shall not assume any liability for errors or omissions in these notes, and your official pilot training should always supersede any information presented herein. As the Canadian PPL curriculum is updated occasionally, I recommend that if you want to be 100% certain that everything in this set of study notes is correct, you should print a copy and ask your instructor to review these notes with you.

If the aircraft type is not specified in the notes below, you should always assume that they refer specifically to characteristics of a Cessna 172M, which is a common training aircraft, and the type that I have used most frequently. Know the characteristics of your own specific training/examination aircraft by memory!

To download PDF or audio MP3 versions of these notes, visit: http://djbolivia.ca/aviation.html

Let's Get Started – Ground School: Navigation

Using the E6B:

- Front Outer scale: Miles travelled, miles per hour, gallons used, gallons/hour, true airspeed.
- Front Middle scale: Time in minutes, indicated airspeed in mph or knots.
- Front Inner scale: Time.
- Numbers on the outer and middle scales can have their decimal places shifted. This cannot be done with the inner scale (time).
- The black triangle on the middle scale represents one hour.

Time/Distance/Speed Calculations - To figure out time to travel a certain distance, line the black triangle on the speed in knots, and under the corresponding number of nautical miles you'll see the number of minutes required. You can also do this with mph and statute miles.

Short Time & Distance – Use the small arrow at 36 (says "seconds") to represent our pointer. The middle scale is then represented by seconds instead of minutes. The inner scale is then represented by minutes instead of hours.

Fuel Consumption – Same as time and distance, just replace mph with gallons per hour, and miles with gallons.

Density Altitude – To figure out the true airspeed, you must know the pressure altitude, the temperature you're flying at, and the indicated airspeed. Use the right windows, line up the CAS (from the IAS) on the middle scale, and you'll see TAS on the outer scale. Density altitude can then be seen in the labelled window.

For **True Altitude** – Use the air temperature and pressure altitude in the left window. The outer scale will read the true altitude and the inner scale will read the calibrated altitude.

Distance Conversion – This is quite simple, and is done entirely on the outer scale. There are arrows for nautical miles, statute miles, and kilometers.

Correcting for Drift – See the E6B manual, or read the instructions printed on the E6B.

On the back side of the E6B, the inner wheel is the spinning azimuth, and the outer wheel is the true index.

Meridian – Semi circles that run from north to south and join at the Earth's true poles. A meridian is half of a great circle.

Prime Meridian – Zero degrees longitude, passes through Greenwich.

International Date Line – Located at 180^{o} longitude, opposite to the prime meridian. This is where the date changes.

One hour (of time) is equivalent to 15^{o} of longitude in rotation.

The equator, at 0^{o} latitude, is both a great circle and a rhumb line.

Azimuth – An angular measurement in a spherical coordinate system. The vector from an observer (origin) to a point of interest is projected perpendicularly onto a reference plane; the angle between the projected vector and a reference vector on the reference plane is called the azimuth. An example is the position of a star in the sky. The star is the point of interest, the reference plane is the horizon or the surface of the sea, and the reference vector points north. The azimuth is the angle between the north vector and the perpendicular projection of the star down onto the horizon.

Great Circle – Any circle that cuts a sphere (such as the Earth) in half. A great circle represents the shortest distance between two points.

Small Circle – Any circle slicing a sphere that isn't a great circle.

A great circle does not cross meridians of longitude at a constant angle, so an aircraft's heading must be changed frequently to follow a track that is a great circle.

Rhumb Lines:

- A curved line on the earth that cuts all meridians through which it passes at the same angle.
- All parallels of latitude (including the equator) are rhumb lines.
- They offer navigators the advantage of following a constant heading, with the disadvantage of not being the shortest distance between two points.

Magnetic Variation (declination) – The angle between magnetic meridians and true meridians.

To convert True to Magnetic, you subtract easterly variation (**east is least, west is best**). This is what you will do for your navigation log. You might have to go in the opposite direction (M to T) on the written exam.

Isogonic Lines – Represent constant magnetic variation. Dashed on a map. They can occasionally have minor bends, due to local disturbances (ie. lots of iron ore in an area).

Agonic Line – The line of 0^o variation. There is one in each of the eastern and western hemispheres.

Magnetic Deviation – Induced by metal and radio equipment in the aircraft.

Swinging the Compass – When a compass is fitted with correction magnets that are adjusted to correct the deviation.

Compass Deviation Card – Notates results after someone "swings the aircraft." The same "east is least, west is best" applies to deviation.

Track:
- A straight line as it has been drawn on a flat map (well, depending on the projection used on the map).
- Tracks are typically True, on the VNC and VTA charts.
- Be aware that a Lo chart compensates for variance, so the track will be magnetic.
- A second definition is possible: a track can also be described as the path that the aircraft travels across the ground.
- A GPS can be set to either true or magnetic, but true is typical.

Heading:
- The direction that the aircraft's nose is pointed in.
- In a navigation log, you usually start out as true, then correct to magnetic (by correcting for variation).
- The heading can be substantially different than the track, depending on wind speed and direction.

True airspeed must be calculated based on positional error, altitude, and temperature.

Ground speed must be calculated based on wind speed and direction.

Bearing – An object's position as measured clockwise from a meridian.

Drift – When the wind blows from the side and causes an aircraft to move away from its intended track.

Air Position – The theoretical position of an aircraft or missile at a given moment, assuming it to have been unaffected in flight by wind. Also known as a no-wind position.

Types of charts include: VNC, VTA, CFS, WAS, DASH, LO, HI, and CAP.

VFR Navigational Chart (VNC):
- This is the VFR chart for low to medium altitudes, the most important en route chart for small GA aircraft.
- Easiest to navigate at altitudes of up to around 7500' AGL.
- Created by Lambert Conformal Conic Projection.
- Lines drawn on this map are great circles.
- Scale is 1:500,000, or one inch equals 8 SM.
- VNC's are usually updated approximately once every two years, whenever significant updates are needed.

VFR Terminal Area (VTA):

- This is the VFR chart for low altitudes, the most important “close to aerodrome” chart for small GA aircraft operating out of airports that are large enough to have such a chart.
- Created by Mercator Transverse Projection.
- A line drawn on these charts will be a rhumb line.
- Scale is 1:250,000, so one inch equals 4 SM.
- Valid times are based on changes.
- This chart is updated approximately every two years, based on whenever significant updates are needed.
- There are VTA charts for Calgary, Edmonton, Montreal, Toronto, Vancouver, Winnipeg, and half a dozen other airports.

Standard Parallel:
- The line of latitude in a conic or cylindrical projection in a normal aspect where the projection surface touches the globe.
- The projection shows no distortion *at* the standard parallel (which visualizes as a ring through a flat map).
- It is possible for a standard parallel to touch the surface of the cone once (tangent conic) or twice (secant conic).

Lambert Conformal Conical projection:
- A conic map projection used for aeronautical charts.
- Used on VNC charts.

Transverse Mercator projection:
- A cylindrical map projection which is the standard for nautical navigation because of its ability to represent lines of constant course (rhumb lines) as straight segments that conserve the angle with the meridians.
- On a world map, the areas at the poles are extremely distorted.
- Used for VTA charts.

Verification Order for charts:
- Make sure the VNC/VTA charts are valid.
- Next, check the “Flight Planning” section in the CFS.
- Finally, check the NOTAM’s.
- The updating sequence is NOTAM → CFS → VNC/VTA.

Lo & High charts:
- For IFR. Below 18,000’ is Lo, and at/above 18,000’ is High.
- Uses lambert conformal conic projection (great circles).
- The scale varies from chart to chart.
- Depict radio aids, airports, and other points of interest to aviation, but no topographical features.
- Valid for 56 days, dates of validity on the front page.
- Ten different coverage areas for Lo charts.
- Six different coverage areas for High charts.
- Charts are smaller in areas of high population and aviation density.

Canada Flight Supplement (CFS):
- Joint civil/military publication.
- Information about all Canadian and North Atlantic registered and certified aerodromes.
- Revised and updated every 56 days.
- Includes a general section, aerodrome directory, flight planning, radio navigation and communications, military, and emergency.

Canada Air Pilot (CAP):

- Amended and republished every 56 days.
- For IFR: Standard instrument approach procedures, and noise abatement procedures.
- Contains SID's and STAR's.
- Different versions for each region. Seven volumes in total, plus CAP GEN which has general pages for all volumes, plus a French version for Quebec.

Water Aerodrome Supplement (WAS):

- Has a directory of all aerodromes shown on VFR charts.
- Revised and reissued annually.

Designated Airspace Handbook (DAH):

- Lists all the airspace and classes in Canada.
- Not well known, but very valuable.
- Contains contact info for CYA's and CYR's.

The WAC, or **World Aeronautical Chart**, is a type of chart that was discontinued by Nav Canada in 2010, and is no longer authorized for operational use. It was replaced by the VNC and VTA charts.

The **VTPC Chart** refers to the VFR Terminal Procedures Chart. When important information about an aerodrome cannot be described by the aerodrome sketch or table in the CFS, a VFR Terminal Procedures Chart is published. The chart contains information on conventional or area navigation procedures for arriving flights established on the basis of airspace organization at the aerodrome.

For the exam, know your chart legends:

- VFR charts: VNC and VTA.
- IFR charts: High and Lo.
- CFS.

The **Longest Runway Distance** (LRD) is listed to the nearest one hundred feet, but the split for rounding up or down is not in the middle, in order to be conservative in a safety sense. It is actually at the 69.5 foot mark of each hundred feet of runway. For example, LRD 53 means a runway length between 5270 and 5369 feet in length.

PNR – Prior Notice Required
PPR – Prior Permission Required
CYD – Airspace, Dangerous

Maximum Elevation Figure (MEF):

- Large digit is thousands of feet, small number is hundreds.
- Feet ASL, rounded up to the nearest 100 for safety.
- Denotes height of the highest feature in each quadrangle, including terrain and obstructions.

Hypsometric Tints – Shadings that illustrate approximate elevations on a chart. The scale will show the highest point obstacle or terrain in feet.

Non-Perennial Lake – May be dry at certain times of the year, similar to an ephemeral stream.

CFS Sections:

- General Section: Legends for VNC/VTA/VTPC charts, explanation of the A&F directory.
- Aerodrome & Facility Directory: Alphabetical listing with comprehensive facility information about all registered land aerodromes in Canada.

- Planning Section: This is a how-to guide for flight plans/itineraries, position reports, PIREP's, equipment code list, transponder operation information, airspace summary, cruising altitude order, weather minima, Koch chart, VFR chart updates.
- Radio Navigation/Communications: Info about various navigation and communication aids.
- Military Flight Data & Procedures: Info for military.
- Emergency Section: Transponder codes, light signals, ELT use, communications failure, intercept procedures.

Obstacle Clearance Circle:
- Lists the highest obstacle altitude above sea level and 1000' rounded up to the nearest 100' increment.
- The radius of the area of control zone is specified on the outer ring of the OCC.

Midnight can be 2400 on the 24hr system.

Mean Solar Day – The interval between two successive passes of the sun over a given meridian of longitude.

The terms longitude and mean time are interchangeable:
- One Time Zone = One Hour of the Earth's rotation = 15º of Longitude.
- One minute of the Earth's rotation = 15' longitude.
- One second of the Earth's rotation = 15" longitude.

Local Mean Time (LMT) – The specific time at a particular meridian. Someone even ten feet away will have a different LMT (unless they are N/S on the same meridian).

True Track – The number of degrees between the direction of flight and True North, as measured clockwise from a longitude line. Also known as True Course (TC).

Three ways to **depart on a cross country**:
1. Overhead departure.
2. Set heading.
3. Direct method.

Set Heading Point:
- Use a point other than the airport.
- Useful because you can't always predict traffic and active runways.
- Gives us the time and distance we may need to get completely organized.
- Pick a point along the track within 15 miles of departure.

Direct Method:
- Pilot turns to the heading and goes.
- Preferred departure method for commercial students.
- Assume this method for all calculations on the written exam.

Overhead Method:
- Climb to cruise altitude while circling over the departure aerodrome, then set appropriate heading while crossing over the airport.

Check Points:
- Before takeoff, study the map and circle/mark a log of prominent landmarks that can help pinpoint position.
- Set up check points for ground speed checks.
- Note distances between check points and also remaining distance to destination.

Using **Position Lines** to obtain a fix:

1. Visualize drawing a line through the center of the heading indicator to the landmarks.
2. Draw these heading lines on a map from the checkpoints.
3. Where these lines cross is your position.

Ground Speed Checks:

1. Before takeoff, find two prominent checkpoints and measure the distance between them.
2. While in flight, use a stopwatch to get the time between the two checkpoints. Be sure to use the minutes and seconds to be as accurate as possible.
3. Divide the time by distance to get a revised ground speed.
4. Use ground speed to calculate the remaining time.

True Track: Apply wind speed to get True Heading.
True Heading: Correction for variation to get Magnetic Heading, then for deviation to get Compass Heading.

A heading is something that we have corrected for wind. A track/course is something that has NOT been corrected for winds.

Always go from True to Magnetic to Compass, whether you are working with tracks or headings:
True Track → Magnetic Track → Compass Track
True Heading → Magnetic Heading → Compass Heading

For cruising altitudes, you fly the compass heading, but for picking your altitude, you need to use magnetic track.

WCA – Wind Correction Angle.

The **Double Cross Chart**, which looks similar to a tic-tac-toe board, is an effective way of figuring out true/magnetic/compass tracks and headings.

Determining Drift with **ten degree lines**:

- It is a good idea to draw two lines from both the point of departure and the destination at a 10° angle on either side of the track.
- This practice is very helpful in correcting for wind drift.
- They correct for upper winds, which cannot always be forecast accurately.

Diversion to an alternate aerodrome:

- You need to be able to quickly estimate a new heading towards a new destination.
- Calculating magnetic heading, distance to be travelled, and new estimated arrival time all require the same fundamental operations that were used before the flight.
- Due to space/time limitations (and flying), the pilot must simplify the calculations.
- To draw the selected route while in flight, do a rough freehand.
- The magnetic track can be calculated by using a compass rose from a VOR.
- The distance may be calculated by latitude lines or by the 10-mile ticks along the original track.
- If you have to divert, make a decision to do it ASAP.
- Your decision may be influenced by fuel, convenience, or easiest navigation. Safety must be a priority.
- Choose carefully when visibility is reduced or when a ceiling makes low altitude navigation necessary.

Reciprocal Track Diversion:

- Essentially, turn around and go back.
- A standard rate turn will take sixty seconds to do a 180° turn.

- Remember to apply your wind correction in the opposite direction!

Low level navigation:
- Watch out for power lines, towers, terrain.
- Keep a finger on the map.
- Fly and trust a constant heading.

Deduced/Dead Reckoning:
- Once you know what you're supposed to be tracking across the ground, look at it and go.
- Used a lot in aviation's early days, before charts or electronic navigation aids were available.
- Based on time, direction, distance only.
- Pilot must know magnetic heading, distance, and rough winds.
- Write down times for each checkpoint passed.

Procedures when lost:
- Remain calm.
- Climb for better visibility and radio range.
- Draw a circle of uncertainty.
- Read the map and identify prominent landmarks. Never assume.
- Use radio aids: Cross track two VOR's or NDB's.
- Contact ATC if necessary.
- A precautionary landing is a last resort.

IAS – Read off the instrument.
CAS – Corrected for instrument/position errors.
TAS – Corrected for temperature/pressure (there is a chart in the POH).

One In Sixty Rule – If you fly one degree off course for 60 NM, then you end up 1 NM off course.

Opening Angle (OA) = (Distance off course / Distance flown) x 60.
Closing Angle (CA) = (Distance off course / Distance remaining) x 60.
Total Course Correction = OA + CA

Three methods of **getting back on track**:
1. Visual alteration.
2. Double track.
3. Opening and closing angles.

Visual Alteration Method:
- Just fly whatever heading you feel like until you are at a point over your original intended track. At that point, start flying again but include a correction that will offset the angle error you originally noticed.

Double Track Error:
- You must be good at timekeeping. Must write down your departure time.
- Take your angle error, double it, and fly that new heading for the same amount of time as your departure to the start of the correction. This will put you back on track.
- Cut your course correction in half at this point.

Opening and Closing Angle:
- Works anywhere along the track.
- Will not re-intercept the track, as the new heading sends you directly to the destination.
- This is the one-in-sixty rule in disguise.

Pilotage – Flying to a destination by hedgehopping or sightseeing, ie. visual landmark references.

Air Position:

- The location of the aircraft after a period of time based only on the course (track) and TAS.
- Would be the same position as a no-wind, so ignore the effects of wind.

Solving for a course with winds:

- Using a wind triangle.
- E6B calculations.
- Flight computer.

Wind Triangle:

- Air Vector: Heading and TAS, dead reckoning position.
- Wind Vector: Wind velocity and direction, the fix.
- Ground Vector: Track and ground speed, air position.

E6B Flight Computer:

- Outer front ring: Speed & distance.
- Middle front ring: Minutes.
- Inner front ring: Hours.
- Left window: Air temperature.
- Right window: Density altitude (inner) and Pressure altitude (outer).
- Black "10" square: Unit index.
- Black "60" triangle: Speed index.

Changing values – You need to carefully watch the changing values of the numerical graduations. The decimal point can be free floating.

The Calculator Side lets you calculate time & distance, short time & distance, fuel consumption, true airspeed, true altitude, density altitude, and simple multiplication and division.

For short time and distance, remember to use the 36 "seconds" marker instead of the black triangle.

On the Wind side of the E6B:

- The center point represents the ground speed.
- The outer ring is the True Index.
- The inner ring is the Rotating Azimuth.

Sliding Grid:

- Represents part of a large graduated circle.
- Lines projecting from the center of the grid and radiating outward represent degrees right or left of the centerline.
- Lines that form the arcs around the center of the circle represent the distance from the center and are labelled in miles.

To determine the total effect of wind on a flight, the true course, true airspeed, and wind velocity must be known.

Altitudes:

- **Pressure Altitude**: What the altimeter reads when set to 29.92 and is correct for standard atmosphere.

- **Density Altitude**: Pressure altitude corrected for temperature. This number tells us how the aircraft will perform.
- **True Altitude**: Corrected for temperature compression errors. This number tells us how high we are.

Airspeeds:
1. **Indicated**: What you see on the dial.
2. **Calibrated**: Corrected for position errors.
3. **True**: Corrected for temperature and altitude.

EET – Estimated Elapsed Time
ETE – Estimated Time Enroute
ETA – Estimated Time of Arrival

Factors affecting the **choice of route**:
- Planning on the ground is better than doing it in the air.
- The most direct route is not always the best.
- You may need to go around water, high ground, or restricted areas.
- Weather and safety are major concerns.
- Remember that the cruising altitude orders start at 3000' AGL.
- Make sure you have current charts.

Map Preparation:
- Don't block out important underlying details.
- Don't use red lines if flying at night.
- Include 10° drift lines (from both directions if your trip will include a return component).
- Mark interval indicators at maybe five or ten mile intervals.
- Include check points for both navigation and foreground speed checks (should be within about 50 NM or thirty minutes flight time in a small GA aircraft).

Do weight and balance reports for both takeoff and landing.

Commercial aircraft must have an approved Minimum Equipment List (MEL) in place.

Snag – A problem found with the aircraft, which gets recorded in the log book. The aircraft needs to remain grounded until the snag is deferred or rectified by an AME.

Conversions:
1 US gallon = 3.78 litres
1 NM = 1.15 SM
1 meter = 3.28 feet

You need to understand how to refer to Cruise Performance Charts (from the POH) to get TAS, fuel burn, and brake horsepower.

When calculating climb data, remember that you are probably not starting from sea level.

Emergency Locator Transmitters:
- Broadcast on 121.5, 243.0, and 406 MHz.
- The new ones are 406's. Satellites don't pick up 121.5 broadcasts anymore, although a 406 still broadcasts on 121.5 MHz.
- Old ELT's had a 25 mW signal, but the new 406's have a 5 watt signal (much stronger).
- If the 406 is GPS enabled, it sends out a burst of data every fifty seconds including a serial number, latitude, and longitude.

- The 406 ELT's are mandatory in all new/changed registrations subsequent to February 1st, 2009.

Types of ELT:
- A/AD: Automatic Ejection or Deployment.
- F/AF: Automatic Fixed.
- AP: Automatic Portable.
- W: Water Activated.
- S: Survival.

ELT's are mandatory for any aircraft more than 25 NM from home base, except for gliders, balloons, airships, ultralights, gyros, and commercial transports.

Testing an old style ELT:
- Only permitted during the first five minutes of any UTC hour, for no longer than five seconds.
- Check 121.5 MHz before shutting down.
- An activated ELT may be strong enough to wash over other frequencies in the aircraft.

Testing a 406 ELT:
- Follow the manufacturer's instructions.
- Can have an on/off/reset switch in the cockpit.
- Monitored by COSPAS-SARSAT geo satellites.
- Do not test for more than fifty seconds or JRCC will interpret it as a real emergency.

Possible toggle switch settings on an ELT:
- OFF: Will not activate.
- ARM: Will activate upon high impact (4 G's).
- ON: Transmitting.

You may encounter a variety of switches on ELT's, with some switches having only two positions and some having three. It's also possible to have slightly different labelling, depending on the unit.

If you're about to "crash" and have a cockpit switch, and you're worried that it might not activate, you could always activate it just a few seconds before impact, then if things go well and you don't need assistance, you have about fifty seconds to disarm it before SAR is activated.

If the ELT can be placed in a high and non-secluded location, SAR will be able to find it more easily. Also, during winter, the battery will last longer if the ELT is kept warm.

If you have an accidental ELT activation, report it ASAP, including the time, location, and duration of transmission.

Electromagnetic Spectrum:
- Long wavelength = low frequency.
- Low frequency = low energy.
- Aviation radio waves (in the MHz) have much lower frequencies than microwave (GHz), infrared (THz), visible light, and above.
- LF is 10 KHz to 30 KHz.
- MF is from 30 KHz to 3 MHz.
- HF is from 3 MHz to 30 MHz.
- VHF is 30 MHz to 300 MHz.
- UHF is 300 MHz to 3000 MHz.
- AM radio broadcasts (600 KHz to 1.6 MHz) are in the MF frequency range.
- NDB's are from 200-600 KHz, surrounded by a bunch of dots on the charts.

- HF is where shortwave is located. HF is used mainly for long range air and ground communications, including oceanic crossings and operations in the high north.
- FM radio is in a narrow segment of VHF.
- UHF is mostly used by military/government, and also by DME equipment.

VHF Frequency Bands:
- TV: 50.00 to 88.00 MHz.
- FM Radio: 88.1 to 107.9 MHz.
- VOR: 108.00 to 117.95 MHz.
- ILS: 108.10 to 111.95 MHz (overlaps a portion of the VOR range).
- Voice (aviation): 118 to 136 MHz.

Ground Waves – Radio waves that follow the surface of the Earth. Able to diffract or bend around obstacles, which causes them to follow the curvature of the Earth.

Surface Attenuation – A method by which ground waves follow the curvature of the Earth. Think of the wave interacting with the Earth and getting tilted downward.

Sky Waves:
- Can be reflected back to Earth by clouds and by the ionosphere, far past the reach of ground waves.
- The ionosphere will be higher at night, which means that reflected waves can reach much further.
- Can be affected by solar activity and other electromagnetic disturbances.
- Relatively free of atmospheric and precipitation static.

Skip Zone – an area on the earth where radio waves don't reach, perhaps because it is too far from a station for ground waves, but bouncing sky waves return to Earth past the zone.

LF/MF/HF – Can use both ground and sky wave frequencies.
VHF/UHF – Propagates almost exclusively as sky waves (line of sight).

Distance of Reception (in miles) = 1.23 multiplied by the square root of aircraft height in feet (AGL).

HF **Single Side Band (SSB):**
- Normal AM signal has a carrier frequency and two side bands, the upper and lower sidebands.
- In SSB, only one of the sidebands is allowed to be transmitted, and the other sideband and carrier are suppressed.
- Once the signal gets to the receiver, the carrier can then be re-inserted.
- Saves a huge amount of power because transmission of just one sideband takes only about one sixth of the regular full signal (the carrier alone takes two-thirds of the power).
- Consumes narrower bandwidth, only 3 KHz instead of 9 KHz normal, conserving spectrum space.
- Eliminates most of the transmission noise.

Automatic Direction Finding (ADF):
- Greater range than VOR's, which are line of sight.
- Being phased out very slowly.
- Low cost of installation, relatively low maintenance costs.
- NDB's and ADF's are parts of the same system. The NDB sends out the signal, which is received by the ADF.
- NDB signal has a significant ground wave component, following the curvature of the Earth, allowing reception at low altitudes and over great distances.
- Most ADF's can also receive AM.
- Type L is up to 50 watts, Type M is between 50 and 2000 watts, and Type H is at least 2000 watts (low/medium/high).

- Limitations of NDB's include errors due to night effect, mountains, shorelines, electrical storms, bank error, ore deposits, fading effect, and two-station interference.

Night Effect:
- Radio waves are reflected by the ionosphere and they return to Earth thirty to sixty miles from the station.
- As the sun rises or sets, the ionosphere will change its position in terms of height above the earth. This can cause the direction of the NDB to appear to change as the reflection angle changes, and it may also cause the ADF pointer to fluctuate.
- This effect is greatest within one hour of sunset or sunrise, at distances greater than thirty miles from the station.
- To mitigate, fly at a higher altitude or select a station with a lower frequency. Frequencies under 350 kHz have very little twilight effect.

Mountains:
- Can reflect radio waves.
- Magnetic deposits in slopes may cause indefinite indications.
- Pilots should only use strong stations that give definite directional indications, and should not use stations obstructed by mountains.

Shorelines:
- Can refract or bend low frequency radio waves as they pass from the land to water.
- A pilot flying over water should not use an NDB signal that crosses over the shoreline to the aircraft at an angle of less than 30^o.
- The shoreline has little or no effect on radio waves that reach the aircraft at angles that are greater than 30^o.

Electrical Storm:
- ADF needle points to the source of lightning because lightning sends out radio waves.
- Pilot should note lightning flashes and not use the indications caused by them.
- Lightning causes the greatest NDB errors.

Precipitation Static:
- Heavy precipitation may cause static when using low and medium frequencies.
- NDB's are more susceptible than VOR's.

Bank Error:
- ADF is subject to errors when the aircraft is placed into a banked attitude, due to the way that the antenna is mounted.
- This is a significant factor during NDB approaches.
- Also known as dip error.

Fading Effect:
- Occurs when ground and sky waves interact, going in and out of phase, causing signals to be either cancelled or reinforced as the atmosphere changes.
- You'll see a rhythmic swinging of the needle and a volume fluctuation of the identifier.
- Most common at night.

Two-Station Interference:
- Caused by congestion in LF/MF bands, when an aircraft can receive signals from two separate NDB's on the same or similar frequencies simultaneously.
- Essentially, this is a phasing error.
- May be more of a problem at night with increased transmission distances.

Relative Bearing – The direction of something (such as an NDB) relative to the nose of the aircraft. It is not a track or heading!

Tuning:
- After tuning the receiver, you must positively identify the station (you should hear a continuous two- or three-unit identification in Morse code).
- LF/MF beacons transmit a signal with 1020 Hz keyed to provide continuous ID except during voice communications.
- If you don't hear the Morse code, don't use the NDB as the rest of the signal may be corrupt.
- Use "receive" mode when tuning.
- After you receive the ident, go to "test" temporarily to check needle deflection.
- Move to ADF setting for normal use.
- After a test, a sluggish return of the needle indicates a signal that is too weak to use.
- The loop antenna is usually a small flat antenna with no moving parts, not an extension/protuberance antenna.
- The loop antenna can't tell if we are to/from a station. The sense antenna does this.
- ADF audio must always be monitored since there is no system failure warning flag.
- NDB's are always green on a map (except on the low VNC, where they are purple). VOR's are black.
- For IFR, during approach/missed/holding, one crew member must aurally monitor beacon idents unless there are instruments that can warn of ADF receiver failure.

Bearing To Station (BTS) – The track to get to the beacon.
Bearing From Station (BFS) – The number of degrees from the station. The opposite of BTS by 180^o.

Magnetic Bearing – The angle formed by the intersection of a line drawn from the aircraft to the radio station and a line drawn from the aircraft to magnetic north. Equals the relative bearing plus the magnetic heading.

Reciprocal Bearing – The opposite of magnetic bearing, add or subtract 180^o from the magnetic bearing. Calculate it when tracking outbound and when plotting fixes.

VOX – Shorthand for voice. Also fits with the acronym for Voice Operated Exchange.

Homing to an NDB – Flying straight at it.

Homing in Winds – The pilot must constantly change magnetic heading to stay on relative bearing of 0^o, which causes a flight arc even though the bearing indicator remains pointed at zero (unless crosswind corrections are made).

Tracking to an NDB:
- Means that you fly straight to the station by correcting for winds.
- The pilot needs to identify it by using both the bearing indicator and heading indicator (different than VOR).
- Sensitivity increases as you get closer to the NDB.

Position Fix by ADF – Use two or more stations and the process of triangulation.

Remember on the exam that we use magnetic headings, but if an examiner asks for a position on a VNC chart, we have to convert from True.

Time Check and **Distance To Station**:
1. Note the BFS and then turn 90^o from the BFS.

2. Note the time in seconds required to cross a certain number of degrees bearing change.
3. Time to Station in Minutes equals the time in seconds divided by the number of degrees changed.
4. Distance to Station = (TAS x Time To Station) / 60.

VOR Navigation:
- VHF Omnidirectional Range.
- Approximately 450 ground based stations in Canada, maintained by Nav Canada.
- Each station broadcasts a unique Morse code identifier, three letters long.
- The VOR Indicator does NOT care about the heading of your aircraft! You can fly in circles while remaining on the same VOR.
- Compass Rose on a chart shows magnetic.
- Transmits between 108.0 MHz and 117.95 MHz.
- Precipitation static and electrical storms are not an issue.
- A tracking accuracy of plus or minus 1^o is possible on a 1^o radial.
- Line of sight only.
- If you're losing the signal, try climbing.
- There are only 160 frequencies and about 450 stations, so you sometimes pick up two signals simultaneously.

Airways:
- The airway system is partially based on VOR's.
- The aircraft's VOR receiver receives an azimuth signal sent from the station.
- This azimuth *From* the station is called a radial of the VOR. The reverse of this radial is the *To* radial, and is 180^o off.
- VOR radials are all based on magnetic.
- It is the *source* of the radial that gives it its name, regardless of which direction the aircraft is going.
- Two main components: the receiver, and the navigation indicator.
- If the VOR receiver and the VHF communications radio are co-located in the same control unit, the radio is called a NAVCOM.
- The VOR navigation indicator (VOR Head) gives the pilot the aircraft's position relative to a specific radial.
- The course index is a small triangle pointing to the selected radial.
- The CDI needle (track bar) helps determine if the aircraft's track is lined up properly.
- The deflection indicators are spaced at 2^o intervals.
- The Red Nav flag, if visible, is the unreliable signal or no signal flag.
- The Omni Bearing Selector (OBS) knob allows us to choose various radials.
- The CDI has a 10^o spread from center to either side when receiving a VOR signal.
- You need to steer in the direction of the CDI deflection to get back on track.

Reference Line:
- When a track is selected, the position of another line is established, which is a reference line perpendicular to the track arrow and intersecting it at the station.
- It divides the VOR reception area into two additional sectors.
- The VOR will temporarily display OFF when passing over this line, even if the crossing point is not over the VOR. This is the Area Of Ambiguity.

Area Of Ambiguity – Occurs when an aircraft is on a radial 90^o to the one that they have selected. It widens with increasing distance from the station.

To **determine a fix** without DME, you can use two VOR stations, and triangulate (remember that a DME gives distance and direction, so triangulation is not necessary):
1. Find a station and twist the OBS until you get a From indicator with the CDI centered.
2. Next, do the same with a second station.

3. Triangulate your chart.

Testing a VOR:

1. VOT Test.
2. Self-test.
3. Apron Check Sign.
4. Dual VOR Check.
5. Geographical Reference Point.

VOT Test:

- Slowly being phased out.
- Stands for VOR Test Frequency, which you must look up in the CFS.
- Set OBS to 360^o. CDI must center to within +/- 4^o and show From.
- Set OBS to 180^o. CDI must center to within +/- 4^o and show To.
- Check full-scale deflection both ways by checking ten degrees from both sides.

VOR Self-Test:

- Found on Cessna radios.
- Tune to any VOR within range, and hold the test toggle down.
- Set OBS to 360^o. CDI must center to within +/- 4^o and show From.
- Set OBS to 180^o. CDI must center to within +/- 4^o and show To.
- Check full-scale deflection both ways by checking ten degrees from both sides.

Apron check:

- Airport sign in a run-up area or somewhere on the apron.
- Taxi up beside sign, follow directions, VOR should be within +/- 4^o.

Dual VOR check:

- Works if your airplane has two VOR receivers.
- Tune both to the same station, select the same radial, they must agree to within +/- 4^o.

Airborne Geographical:

- Fly over a landmark on a known and published radial, and note the indicated radial.
- Must be +/- 6^o, this is the only method that allows for greater than a four degree variance.

Time & Distance check to station – Uses exactly the same approach and formulas as with the NDB, except using radials instead of degrees (the same thing).

Primary Surveillance Radar (PSR) does not require an interrogation. It displays reflected radio signals from contacts, aircraft, and weather. Being phased out.

Secondary Surveillance Radar (SSR) requires a reply from a transponder (interrogation) to determine the aircraft's range. Does not locate weather. Much better range than the PSR.

Area Navigation (RNAV):

- Can be defined as a method of navigation that permits aircraft operation on any desired course within the coverage of the station referenced navigation.
- No airways required.
- Developed to provide more lateral freedom and thus more complete use of available airspace.
- Includes GPS as one possible system.
- Does not require a track to/from any specific radio navigation aid.
- A route structure can be organized between any given departure and arrival point to reduce flight distance and traffic separation.

- Aircraft can be flown into terminal areas on varied pre-programmed arrival and departure paths to expedite traffic flow.
- Instrument approaches can be developed and certified at certain airports, without local instrument landing aids at that airport.
- Types include Multiple VOR/DME, GNSS (GPS), Inertial Navigation Systems (INS), or Inertial Reference Systems (IRS).

VOR/DME Method:
- The Track Line Computer (TLC) system is based on azimuth and distance information from a VORTAC. Also called the Rho-Theta system.
- Pilot effectively moves or offsets the VORTAC to any desired location (if it is within reception range).
- The phantom station is created by setting the distance (Rho) and the bearing (Theta) of the waypoint from a VORTAC.
- Use a series of these phantom stations to make up an RNAV route.
- Disappearing due to the prevalence of GPS.

Inertial Navigation Systems:
- Completely self-contained and independent of ground-based navigation aids.
- After being supplied with initial position information, it is capable of updating with accurate displays of position, attitude, and heading.
- Can give track and distance between two points, course error, ETA, ground speed, and wind information.
- Can provide guidance and steering info.
- Works due to accelerometers and gyroscopes.
- System alignment before flight is important.
- Accuracy decays at about 1-2 NM/hr.
- Position updates can be implemented in flight.

Flight Management System:
- An integrated system that uses navigation, atmospheric, and fuel flow data from several sensors to provide a centralized control system for flight planning and for flight/fuel management.
- Controls vary widely between aircraft.
- Multi-sensor, including DME, VOR, air data computer, and fuel flow sensors.
- May also incorporate INS, IRS, and GPS.
- Most are approved for en route IFR.

Tactical Air Navigation (TACAN):
- Used primarily by military, works like a VOR/DME.
- Provides azimuth (radials) and slant distance (NM) from ground station.
- 126 UHF channels.
- Civilian pilots trying to tap into it will receive only DME. Any VOR radial info would be a false signal.

Radar Altimeter – Provides dependable, accurate altitude AGL.

Flight Director System:
- Electronically collects info from several sources.
- Includes a Horizontal Situation Indicator and an Attitude Director Indicator.
- Can be used with or without autopilot.
- Command bars placed over top of the attitude indicator. The pilot keeps them aligned.

Airborne Collision Avoidance Systems (ACAS) and Traffic Alert & Collision Avoidance Systems (TCAS) both receive SSR equipped aircraft (transponders) and the computer calculates if there is a chance of a collision.

DF Steer – Directional assistance to an aircraft using radio. Essentially phased out in Canada now.

Global Navigation Satellite System (GNSS):

- Up to 32 satellites in orbit.
- Satellites in polar orbits, circling Earth in just under 12 hours.
- GPS satellites are referred to as NavStar.
- Need to triangulate from three satellites for two dimensions (latitude and longitude).
- Need a fourth satellite to also get an altitude/elevation position fix.
- Advantages include: Point to point navigation, not affected by weather, unlimited range, very accurate, economical, available 24/7.
- Always verify the coordinates of a waypoint! Think it out, don't just stare at the digits and let your eyes glaze over. Maybe you can verify from a CFS or map chart.
- Do not rely solely on the GPS.
- Orbit at 11,900 NM, six different orbital paths, each satellite transmitting on 1227.6 MHz and 1575.42 MHz.
- Virtually no errors due to atmospheric distortion.
- Line of sight, so watch out for signal masking.
- Each GPS satellite has four atomic clocks to ensure accuracy.
- There is a master control station in Colorado Springs that has the capability to send corrections to satellites if errors are detected.
- Be aware that GPS gives true tracks and ground speeds (not airspeed).

Differential GPS:

- Used to achieve the accuracy required for more demanding operations.
- Done by having a receiver on the ground at a precisely surveyed position.
- The data can be "corrected" with cross reference from the ground station.
- Two types: WAAS and LAAS.

Wide Area Augmentation System (WAAS):

- A network of ground-based reference stations create a correction signal which is sent to WAAS geo-stationary satellites.
- Compatible devices receive the correction signal from the satellite and improve upon accuracy.

Local Area Augmentation System (LAAS):

- An all-weather aircraft landing system based on real-time differential correction of the GPS signal.
- Local reference receivers located around the airport send data to a central location at the airport.
- This is the basis for a correction message, which is transmitted to users via a VHF data link.
- Aircraft's receiver corrects GPS data with this message, and an ILS-style precision approach display becomes available.

System Integrity – The ability of a system to warn a user when there is something wrong with it. If ILS detects a malfunction, it shuts down, flags, and you have to do a missed approach.

RAIM – Receiver Autonomous Integrity Monitoring (an integrity assessment system).
FDE – Fault Detection & Exclusion.

Baro-Aiding – A type of GPS integrity augmentation that basically allows your GPS to use your static system to provide a vertical reference and reduce the number of satellites required in a RAIM system.

A GPS installation must have prior approval before it can be used in IFR conditions (TSO C-129 Standard).
Handheld devices will not be approved.

Be careful when entering GPS coordinates. For example, CWYG (the airport) and WYG (the VOR for that airport) seem like they should be the same, but they are listed at different coordinates. User entered waypoints are the most common source of GPS error.

Do not navigate solely with GPS!

Transponder:

- A radio receiver/transmitter which will generate a reply signal upon proper interrogation, designed to reinforce a surveillance radar signal.
- Consists of a controller, a receiver/transmitter, and a k-Band antenna that looks like an inverted shark's fin.
- The ground station is a rotating directional antenna (you'll see a light blinking on the transponder when the ground antenna rotates toward you and does an interrogation).
- Mode C has a pressure altimeter in it that gives apparent elevation, ie. asks for identification and altitude.
- Mode A asks for identification only.
- Mode S also incorporates a unique signature, so you don't have to dial a specific transponder code.
- You can tell you have Mode C if you have an ALT setting.

Squawk – To operate the transponder on a specified code, or to activate certain modes or functions on the transponder.

Squawk Ident – Push the IDENT button. Only do this if ATC requests it.

Stop Squawk – Turn off your transponder.

Transponder Codes:

1000: General IFR below 12,500' ASL.
1200: General VFR below 12,500' ASL.
1400: General VFR above 12,500' ASL.
2000: General IFR above 12,500' ASL.
7500: Hijack.
7600: Communications Failure.
7700: Emergency.

Grivation – The angle between north as indicated by a grid on a map and magnetic north at any point.

Conclusion

The topics included in a study of navigation for aviation have a greater scope than I've covered here. It would also be wise to spend quite a bit of time studying the various publications that I've linked to on this page: http://www.djbolivia.ca/aviation.html

I have links there to several additional aviation-related publications.

Thanks for reading, I hope this was helpful to pilots in training. If you find any errors in the above information, feel free to contact me at jonathan.scooter.clark@gmail.com

- Jonathan Clark