II.A. Aircraft Flight Instruments & Navigation Equipment

References: FAA-H-8083-3; POH/AFM

Objectives  The student should develop knowledge of the elements related to the operation of flight instruments as well as the characteristics and operation of navigation equipment.

Key Elements  1. Pitot/Static Errors
               2. Compass Corrections
               3. VOR Navigation

Elements  1. Flight Instruments
           2. Navigation Equipment
           3. Ant-ice/Deicing and Weather Detection Equipment

Schedule  1. Discuss Objectives
           2. Review material
           3. Development
           4. Conclusion

Equipment  1. White board and markers
            2. References

IP’s Actions  1. Discuss lesson objectives
              2. Present Lecture
              3. Ask and Answer Questions
              4. Assign homework

SP’s Actions  1. Participate in discussion
              2. Take notes
              3. Ask and respond to questions

Completion Standards  The student can describe the different flight and navigation instruments and their operation, as well as potential errors associated with the instruments.
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Instructors Notes:

Introduction:

Attention
Interesting fact or attention grabbing story

Overview
Review Objectives and Elements/Key ideas

What
An explanation of how your flight instruments and navigation instruments parts and operation, the errors associated with them, as well as their proper use.

Why
A thorough understanding of the operation of the flight instruments is necessary in order to understand the errors and potential problems associated with them. An understanding of the different types of navigation equipment is important for proper use in flight.

How:
1. Flight Instruments
   A. Pitot-Static System (Altimeter, VSI, ASI)
      i. How it Works
         a. Flight instruments depend on accurate sampling of the ambient atmospheric pressure
            • This is used to determine the height and speed of movement of the aircraft through the air
         b. Static Pressure (still air pressure) is measured at a flush port where air is not disturbed
            • Pressure of the air that is still or not moving, measured perpendicular to the aircraft surface
         c. Pitot Pressure (impact air pressure) is measured through a tube pointed into the relative wind
            • Ram air pressure used to measure airspeed
         d. The Pitot Tube connects to the ASI; the Static Port connects to all 3 instruments
      ii. Sensitive Altimeter
         a. An aneroid barometer that measures the absolute pressure of the ambient air and displays it as feet above a selected pressure level
         b. Principle of Operation
            • The sensitive element is a stack of evacuated, corrugated bronze aneroid capsules
            a. Air pressure tries to compress them, while natural springiness tries to expand them
            b. This results in their thickness changing as their air pressure changes
               1. The change in thickness moves the gears/linkages to change the altitude displayed
            • Contains an adjustable barometric scale (visible in the Kollsman window)
            a. This allows you to set the reference pressure from which the altitude is measured
            b. Rotating the knob changes the barometric scale: 1” Hg is equal to 1,000’
               1. Standard pressure lapse rate below 5,000’
            c. Pressure altitude is when the kollsman window is set to 29.92” Hg
            d. When you want to display indicated altitude, adjust to the local altimeter setting
               1. This will indicate the height above the existing sea level pressure
         c. Errors (Mechanical and Inherent)
            • Nonstandard Temperature
            a. When in warmer than standard air, air is less dense and pressure levels are farther apart
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1. At 5,000’ indicated, true altitude is higher than it would be if the air were cooler
   a. The pressure level for that alt is higher than it would be at standard temp
   b. If air is colder than standard, it is denser, and pressure levels are closer together

   1. At 5,000’ indicated, true altitude is lower than it would be if the air were warmer
      a. The pressure level for that alt is higher than it would be at standard temp

• Nonstandard Pressure
  a. High pressure to Low pressure
     1. If the pilot does not change the altimeter settings, the altimeter will indicate lower
     2. As the pressure decreases, the altimeter reads it as though the airplane is climbing
        a. The Altimeter increases although the airplane is at the same altitude
           i. To compensate for this the pilot will descend, therefore lowering true alt

  b. The opposite applies from Low pressure to High pressure

• REMEMBER: From hot to cold, or from high to low, look out below!

iii. Vertical Speed Indicator
   a. A rate-of-pressure change instr. giving an indication of deviation from a constant pressure level
   b. Principle of Operation
      • Inside the instrument case is an aneroid
         a. Both the aneroid and the inside of the instrument case are vented to the static system
            1. But, the case is vented through a calibrated orifice that causes the pressure inside to change more slowly than that inside the aneroid
      • As the aircraft ascends, the static pressure becomes lower (Descent is the opposite)
         a. The pressure inside the case compresses the aneroid, moving the pointer upward
      • When the aircraft levels off, the pressure no longer changes
         a. The pressure inside the case becomes the same as that inside the aneroid

iv. Airspeed Indicator
   a. A differential pressure gauge measuring the dynamic pressure of the air the aircraft is in
      • Dynamic Pressure: the difference in ambient static air pressure and the total, or ram, pressure caused by the motion of the aircraft through the air
   b. Principle of Operation
      • Consists of a thin, corrugated phosphor bronze aneroid, or diaphragm, receiving its pressure from the pitot tube
      • The instrument is sealed and connected to the static port(s)
      • As pitot pressure increases/static decreases, the diaphragm expands and vice versa
         a. A rocking shaft and set of gears drives the AS needle

B. Gyroscopic System (AI, HI, TC)
   i. How it Works
      a. The 2 characteristics of gyroscopes: Rigidity and Precession
         • Rigidity: Characteristic that prevents its axis or rotation tilting as the Earth rotates
         • Precession: Characteristic that causes an applied force to be felt 90° from that point in the direction of rotation
   b. The instruments contain a gyro (small wheel with its weight concentrated around its periphery)
      • When spun at a high speed, the wheel becomes rigid, resisting any attempt to tilt or turn in any direction other than around its spin axis
         a. Attitude/Heading instruments operate on the principle of rigidity
            1. The gyro remains rigid in its case and the aircraft rotates about it
      • Rate indicators (turn indicators/turn coordinators) operate on the principle of precession
a. The gyro precesses (or rolls over) proportionate to the rate the aircraft rotates about one or more of its axis

c. Power Sources
   • Electrical Systems
   • Pneumatic Systems
     a. Driven by a jet of air impinging on buckets cut into the periphery of the wheel
   • Venturi Tube Systems
     a. Air flows through venturi tubes mounted on the outside of the aircraft
       1. The constricted part of the tube (low pressure) is connected to the instruments
          a. This creates a suction
   • Wet-Type Vacuum Systems
     a. Steel vane air pumps are used to evacuate the instrument cases
     b. The vanes in the pumps are lubricated with oil which is discharged with the air
     c. Excess air can be used inflate deicer boots

• Dry-Air Pump Systems
  a. At high altitudes, more air is needed in the instruments as the air is less dense
     1. Air pumps that do not mix oil with the discharge air are used in high flying
  b. Vanes are made of a special formulation of carbon which do not need lubricating
• Pressure Systems
  a. 2 dry air pumps are used with filters to filter anything that could damage the fragile carbon vanes in the pump
  b. The discharge air from the pump flows through a regulator, where excess air is bled off to maintain the pressure in the system at the desired level
  c. The regulated air then flows through inline filters to remove any contamination that could have been picked up from the pump, and from there into a manifold check valve
  d. If either engine becomes inoperative, or if either pump fails, the check valve will isolate the inoperative system and the instruments will be driven by air from the other system
  e. After passing through the instruments/driving the gyros, air is exhausted from the case
  f. The gyro pressure gauge measures the pressure drop across the instruments
ii. Attitude Indicator
   a. Principle of Operation
      • Its operating mechanism is a small brass wheel with a vertical spin axis
         a. It is spun by either a stream of air on buckets cut into its periphery or an electric motor
      • Mounted in a double gimbal which allows the aircraft to pitch and roll about the gyro
         a. A type of mount in which the axes of the two gimbals are at right angles to the spin of the axis of the gyro allowing free motion in two planes around the gyro
      • A horizon disk is attached to the gimbals so it remains in the same plane as the gyro
         a. The airplane pitches and rolls around the horizon disk
      • A small aircraft is put in the instrument case so it appears to be flying relative to the horizon
         a. The aircraft can be raised or lowered
      • To function properly, the gyro must remain vertically upright while the aircraft pitches/rolls
         a. The bearings have a minimum of friction, but even the small amount causes precession
            1. To minimize tilting, an erection mechanism applies a force any time the gyro tilts to return it to the upright position
   b. Errors
      • Free from most errors, but...
         a. There may be a slight nose-up indication during a rapid acceleration and vice versa
         b. There is also the possibility of a small bank angle and pitch error after a 180° turn

iii. Heading Indicator
   a. The gyro is mounted in a double gimbal axis in such a way that its spin axis is horizontal
      • Senses rotation about the vertical axis of the airplane
   b. Must be set to the appropriate heading by referring to a magnetic compass
      • Rigidity causes them to maintain this heading indication
   c. Air driven: air flows into the case, blowing against buckets in the periphery of the wheel
   d. The instrument should be checked every 15 minutes to ensure it matches the magnetic compass

iv. Horizontal Situation Indicator (HSI)
   a. A direction indicator which combines the MC with nav signals and a glide slope
      • Uses the output from a flux valve to drive the dial, which acts as the compass card
      • All of this gives an indication of location with relationship to the course chosen

v. RMI
   a. A typical system consists of an HSI, the slaving control and compensator unit
   b. Slaving Control and Compensator Unit
      • Has a pushbutton means of selecting either slaved or free gyro mode
      • Also has a slaving meter and 2 manual heading drive buttons
         a. Slaving meter indicates the difference between displayed heading and magnetic heading
         b. In free gyro mode, the card is adjusted with the appropriate heading drive button
      • The magnetic Slaving Transmitter
         a. A separate unit mounted remotely (usually in the wingtip), to eliminate interference
         b. Contains the flux valve, which is the direction sensing device of the system
            1. The signal relayed to the HI operates a torque motor which precesses the gyro until aligned with the transmitter signal

vi. Turn Indicators
   a. Rate instruments operate on the principle of precession
   b. Turn-and-Slip Indicator
      • A small gyro mounted in a single gimbal
         a. Gyro spin axis is parallel to the lateral axis; the gimbal axis is parallel to the longitudinal
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- Yawing, or rotating about the vertical axis, produces a force in the horizontal plane
  a. This, due to precession, causes the gyro and its gimbal to rotate about the gimbal axis

- Inclinometer
  a. A black glass ball sealed inside a curved glass tube that is partially filled with a liquid
  b. When straight and level, there is no inertia acting on the ball and it remains centered
  c. In a turn with too steep a bank angle, gravity exceeds inertia and the ball rolls inward
  d. In a turn with too shallow of bank, inertia exceeds gravity and the ball rolls outward
  e. Only indicates the relationship between the angle of bank and the rate of yaw

- Turn Coordinator
  a. Similar to the Turn and Slip Indicator, but its gimbal frame is angled upward about 30° from the longitudinal axis of the airplane
  b. This allows it to sense both roll and yaw (not just yaw like the T&S Indicator)
  c. The inclinometer is the same, and called a coordination ball
  i. Shows the relationship between the bank angle and rate of yaw
    1. Skidding when the ball rolls outside the turn
    2. Slipping when the ball rolls inside the turn

C. Magnetic Compass

i. Operation
   a. Two small magnets attached to a metal float sealed inside a bowl of clear compass fluid
   b. A card is wrapped around the float and visible from the outside with a lubber line
      i. Lubber Line: The reference line used in a magnetic compass or heading indicator
   c. The float/card has a steel pivot in the center riding inside a spring loaded, hard glass jewel cup
      i. The buoyancy of the float takes most of the weight off the pivot
      ii. The jewel and pivot type mounting allows the float to rotate and tilt up to approx 180°
   d. The magnets align with the Earth’s magnetic field and direction is read opposite the lubber line
      i. The pilot sees the card from its backside
         a. The reason for this is the card remains stationary and the housing/pilot turn around it

ii. Errors
   a. Variation
      i. Caused by the difference in the locations of the magnetic and geographic north pole
      ii. The north magnetic pole is not collocated with the geographic north pole
          a. The difference between true and magnetic directions
      iii. Isogonic Lines: Lines drawn across aeronautical charts connecting points have the same magnetic variation
      iv. Agonic Line: An irregular imaginary line across the surface of the Earth along which the magnetic and geographic poles are aligned and along which there is no magnetic variation
   b. Deviation
      i. Caused by local magnetic fields within the aircraft; different on each heading
      ii. The magnets in a compass align with any magnetic field
          a. Local magnets caused by electrical currents will conflict with the Earth’s field
      iii. Deviation varies by heading and is shown on a compass correction card
   c. Finding the Compass Course
      i. True Course ± Variation = Magnetic Course ± Deviation = Compass Course
      ii. Remember: East is Least, West is Best
          a. Subtract variation from true course, Add variation to true course


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d. Dip Errors
   - What’s Going On
     a. The lines of magnetic flux are considered to leave the Earth at the magnetic N pole and
        enter at the magnetic S pole
     1. At both poles, the lines are perpendicular to the surface
     2. Over the equator, the lines are parallel to the surface
     b. The magnets align with these fields and near the poles they dip, tilt, the float/card
     c. The float is balanced with a small dip compensating weight, so it stays relatively level
   - Northerly Turning Error
     a. Caused by the pull of the vertical component of the Earth’s magnetic field
     b. When flying on a heading of N, a turn to the E results in:
        1. The aircraft banking to the right and the compass card tilting to the right
        2. Then, the vertical component pulls the N seeking end of the compass to the right
           a. The float rotates, causing the card to rotate toward the W (opposite the turn)
        c. The same happens when turning to the W; the float rotates to the E (opposite)
     d. Remember: When starting a turn from a N heading, the compass lags behind the turn
     e. When flying on a heading of S, a turn to the E results in:
        1. The Earth’s field pulling on the end of the magnet that rotates the card toward the E
           (same as the turn)
     f. When turning to the W, the same happens; the float rotates to the W (same direction)
     g. Remember: When starting a turn from a S heading, the compass leads the turn
     h. Remember: UNOS - Undershoot North, Overshoot South
   - Acceleration Error
     a. The dip-correction weight causes the end of the float and card marked N (S seeking end)
        to be heavier than the opposite end
     b. If the aircraft accelerates on a heading of E, the inertia of the weight holds its end of the
        float back, and the card rotates toward the N
     c. If the aircraft decelerates on a heading of E, inertia causes the weight to move ahead
        and the card rotates to the S
     d. When flying on a heading of W, the same things happen
     e. Remember: ANDS – Accelerate → North, Decelerate → South
   e. Oscillation Error
      - Oscillation is a combination of all the other errors
      a. It results in the compass card swinging back and forth around the heading being flown
      b. When setting the HI to the MC, use the average indication

2. Navigation Equipment
   A. Very High Frequency Omni-Directional Range (VOR)
      i. Three types of VORS
         a. VOR – The VOR by itself, provides magnetic bearing information to and from the station
         b. VOR/DME – When DME (Distance Measuring Equipment) is also installed with the VOR
         c. VORTAC – When military tactical air navigations (TACAN) equipment is installed with a VOR
            • DME is always an integral part of a VORTAC
      ii. What is it?
         a. Omni means all
            • An omnidirectional range is a VHF radio transmitting ground station that projects straight
              line courses (or radials) from the station in all directions
              a. It can be visualized from the top as being similar to the spokes from the hub of a wheel
b. The distance the radials are projected depends on the power output of the transmitter
c. The radials projected are referenced to magnetic north
   1. A radial is defined as a line of magnetic bearing extending outward from the VOR station
   2. The accuracy of course alignment with radials is considered to be excellent (within +/- 1°)
d. VOR ground stations transmit within a VHF frequency band of 108.0 – 117.95 MHz
   1. Because the equipment is VHF, the signals are subject to line-of-sight restrictions
      a. Therefore, range varies in direct proportion to the altitude of the receiving equipment
e. VORs are classed according to operational use in 3 classes with varying normal useful ranges:
   1. T (Terminal); L (Low Altitude); H (High Altitude)

### Class | Alitudes               | Radius (Miles) |
---------|------------------------|----------------|
**T**    | 12,000’ and Below      | 25             |
**L**    | Below 18,000’          | 40             |
**H**    | Below 14,500’          | 40             |
**H**    | 14,500 – 17,999’       | 100            |
**H**    | 18,000’ – FL 450       | 130            |
**H**    | FL 450 – 60,000’       | 100            |

iii. VOR Checks
a. The best assurance of maintaining an accurate VOR receiver is periodic checks and calibrations
   1. Not a regulation for VFR flight
b. Checks (checkpoints are listed in the A/FD)
   1. FAA VOR Test Facility (VOT)
   2. Certified Airborne Checkpoints
   3. Certified Ground Checkpoints located on airport surfaces
   4. Dual VOR check
c. Verifies the VOR radials received are aligned with the radials the station transmits
d. IFR tolerances required are +/- 4° for ground checks and +/- 6° for airborne checks

iv. Using the VOR
a. Identifying It
   1. Station can be identified by its Morse code ID or a voice stating the name and VOR
   2. If the VOR is out of service, the coded identification is removed and not transmitted
      a. It should not be used for navigation
   3. VOR receivers have an alarm flag to indicate when signal strength is inadequate
      a. The plane is either too far or too low and is out of the line-of-sight of the signal
b. There are 2 required components for VOR radio navigation
   1. The ground transmitter and the receiver
      a. Transmitter is at a specific position on the ground and transmits on an assigned frequency
      b. Airplane equipment includes the receiver with a tuning device and a VOR instrument
         1. The navigation instrument consists of:
            a. An OBS (Omnibearing Selector), referred to as the course selector
            b. A CDI (Course Deviation Indicator) Needle
            c. A To/From Indicator
   2. Course selector is an azimuth dial that is rotated to select a radial/determine the radial on
      a. In addition, the magnetic course TO or FROM the station can be determined
   3. When the OBS is rotated, the CDI moves showing the radial relative to the airplane
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- If centered, the CDI will show the radial (MC FROM)/its reciprocal (MC TO)
- The CDI will also move to the right or left if the airplane is away from the radial selected
  c. TO and FROM
- By centering the needle, either the course “FROM” or “TO” the station will be indicated
  a. If the flag displays “TO,” the course on the course selector must be flown to the station
  b. If “FROM” is displayed and the course followed, the plane flies away from the station

v. VOR Tips
  a. Positively identify the station by its code or voice identification
  b. Remember, VOR signals are line-of-sight
  c. When navigating TO, determine the inbound radial and use it (Don’t reset radial, correct drift)
  d. When flying TO a station always fly the selected course with a TO indication
  e. When flying FROM a station always fly the selected course with a FROM indication

B. Distance Measuring Equipment (DME)
  i. Function
    a. When with a VOR, DME can determine position, including bearing and distance TO/FROM
    b. Used for determining the distance from a ground DME transmitter
    c. The info can be used to determine position or fly a track at a constant distance from a station
  ii. How it Works
    a. The aircraft DME transmits interrogating RF pulses which a DME antenna on the ground receives
    b. The signal triggers ground receiver equipment to respond back to the interrogating aircraft
    c. The airborne DME measures the elapsed time between the sent signal and the reply signal
      • The time measurement is converted into NMs from the station
    d. Some receivers provide GS by monitoring the rate of change of position to the station
    e. DME operates on UHF frequencies between 962 MHz and 1213 MHz
  iii. Components
    a. Ground Equipment
      • VOR/DME, VORTAC, ILS/DME, and LOC/DME provide DME course and distance info
    b. Airborne Equipment
      • An antenna and a receiver
    c. Pilot Controllable Features
      • Channel (frequency) Selector: To select the proper channel/frequency for the desired
      • On/Off/Volume: Can be used to identify the DME (Morse code plays 1x for every 3-4x VOR)
      • Mode Switch: Cycles between Distance, GS and time to station
      • Altitude: Some correct for slant range error
  iv. Errors
    a. DME signals are line of sight
    b. Slant Range Distance
      • The mileage readout is the straight line distance from the aircraft to the ground facility
      • Differs from the distance from the station to the point on the ground beneath the aircraft
      • This error is the smallest at low altitudes and long range
        a. It is greatest when over the ground facility, when it will display altitude above
        b. Negligible if 1 mile or more away from the facility for each 1,000’ above facility elevation

C. Instrument Landing System (ILS)
  i. An electronic system that provides both horizontal and vertical guidance to a specific runway, used
to execute a precision instrument approach procedure
  ii. Ground Components
    a. Localizer: Provides horizontal guidance along the centerline of the runway
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- The portion of the ILS that gives left/right guidance info down the centerline of the instrument runway for final approach
  - Located on the extended centerline
  - Radiates a field pattern, which develops a course down the centerline toward the MM/OMs
    a. Also radiates a similar course along the runway centerline in the opposite direction
      1. These are the front and back courses, respectively
  - Provides course guidance between 108.1 and 111.95 MHz (odd tenths only)
    a. Guidance is given from 18 nm from the antenna up to 4,500’ above antenna elevation
  - Localizer Course is very narrow, normally 5°
    a. A full scale deflection shows when 2.5° to either side of the centerline
      1. With no more than ¼ scale deflection, the airplane will be aligned with the runway

b. Glide Slope: Provides vertical guidance toward the runway touchdown point, usually a 3° slope
  - Part of the ILS that projects a radio beam upward at an angle of approx 3° from the approach end of an instrument runway to provide vertical guidance for final approach
  - Equipment is housed in a building approx 750-1250’ down from the approach end of the runway, and 400-600’ to one side of the centerline
  - The course projected is basically the same as a localizer on its side
    a. The projection angle is normally 2.5-3.5° above the horizontal
      1. This intersects the MM at about 200’/OM at about 1,400’ above runway elevation
  - Only radiates signal in the direction of the final approach on the front course
  - Normally a 1.4° thick glidepath (at 10 nm, this equals 1,500’ and narrows to a few feet at TD)

c. Marker Beacons: Provide range info along the approach path
  - A low powered transmitter that directs its signal upward in a small, fan shaped pattern.
  - Used along the flightpath when approaching an airport for landing, marker beacons indicate, both aurally and visually, when the aircraft is directly over the facility
  - Two VHF marker beacons, Outer and Middle, are normally used in the ILS system
    a. A third beacon, Inner, is used where Category II ops are certified
  - The Outer Marker (OM)
    a. Located on the localizer front course 4 to 7 miles from the airport
    b. Indicates where, when at the appropriate alt, on the localizer one will intercept glidepath
  - The Middle Marker (MM)
    a. Approx 3,500’ from the landing threshold on the centerline of the localizer front course
    b. It is at a position where the glide-slope centerline is about 200’ above the landing threshold
  - The Inner Marker (IM)
    a. Located on the front course between the MM and the landing threshold
    b. Indicates the decision height on a Category II ILS approach
  - Compass Locator
    a. Low powered NDBs which are received and indicated by the ADF receiver
    b. When used in conjunction with an ILS front course, the compass locator facilities are collocated with the outer and/or MM facilities

d. Approach Lights: Assist in the transition from instrument to visual flight
  - Visual stage of the instrument approach
    a. The landing is continued with reference to runway touchdown zone markers
  - Visual identification of the ALS must be instantaneous, so it’s important to know the type
    a. ALSF, SSALR, MALSR, REL, MALSF, ODALS, also VASIs
ii. Airborne Components: Include receivers for the:
   a. Localizer
      • Typical VOR receiver is also a localizer receiver and functions the same way
   b. Glide Slope
      • Glide slope is tuned automatically to the proper frequency when the localizer is tuned
      • Each localizer frequency is paired with a corresponding glide slope frequency
   c. Marker Beacon
      • OM
         a. Low-pitch tone
         b. Continuous dashes at the rate of 2 per second
         c. Purple/blue marker beacon light
      • MM
         a. Intermediate tone
         b. Alternate dots and dashes at a rate of 95 dot/dash combinations per minute
         c. Amber marker beacon light
      • IM
         a. High-pitched tone
         b. Continuous dots at the rate of 6 per second
         c. White marker beacon light
   d. ADF
   e. DME
   f. And the respective indicator instruments

iv. Other components (not specific components but may be incorporated for safety and utility)
   a. Compass Locators: Provide transition from en route NAVAIDS to the ILS system
      • Assist in holding procedures, tracking the localizer course, identifying marker beacon sites,
        and providing a FAF for ADF approaches
   b. DME collocated with Glide Slope Transmitter: Provides positive distance to touchdown info

v. Three Types
   a. Category I: Provide for approach to a height above touchdown of not less than 200’
   b. Category II: Provide for approach to a height above touchdown of not less than 100’
   c. Category III: Provide lower minimums for approaches without a decision height minimum
      • II and III require special certification for the pilots, as well as ground/airborne equipment

vi. Errors
   a. Reflection: Surface vehicles/aircraft below 5,000’ AGL may disturb the signal
   b. False Courses: GS facilities inherently produce additional courses at higher vertical angles
      • If the approach is made at the altitudes shown on the charts, they won’t be encountered

D. Automatic Direction Finder (ADF)
i. The NDB is a ground based radio transmitter that transmits radio energy in all directions
   a. The ADF, when used with an NDB, determines the bearing from the aircraft to the station
ii. The ADF needle points to the NDB ground station to determine the relative bearing
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a. **Relative Bearing**: The number of degrees measured clockwise between the heading of the aircraft and the direction from which the bearing is taken

iii. **Magnetic Heading + Relative Bearing = Magnetic Bearing**
   a. Mary Had+Roast Beef= Mary Barfed
   b. Magnetic Heading: The direction an aircraft is pointed with respect to magnetic North
   c. Magnetic Bearing: The direction to or from a radio transmitting station measured relative to magnetic North

d. **NDB Components**
   - The ground equipment, the NDB, which transmits between 190 to 535 KHz
   - The aircraft must be in operational range of the NDB
     a. Depends on the strength of the station

e. **ADF Components**
   - The airborne equipment; includes 2 antennas, a receiver, and the indicator instrument
   - Antenna
     a. Sense Antenna: (Non directional) Receives signals nearly equally from all directions
     b. Loop Antenna: (Bi directional) Receives signals better from 2 directions
     c. When put together in the ADF it can receive well in all directions but 1
       1. Therefore, resolving any directional ambiguity
   - Indicator Instrument
     a. 3 kinds: Fixed card ADF, Movable Card ADF, or the RMI
     b. Fixed Card ADF
       1. Always indicates 0 at the top and the needle indicates RB to the station
     c. Movable Card ADF
       1. Rotates to allow the current heading to be at the top of the instrument
       a. This allows the head of the needle to indicate the MB to the station
       b. The tail indicates MB from the station
     d. RMI
       1. Automatically rotates the azimuth card to represent aircraft heading
       2. Has 2 needles which can be used for nav info from either the ADF or VOR receivers
       3. When the ADF is driving the needle, the head indicates MB TO the station tuned
          a. The tail is the MB FROM the station tuned
       4. With the VOR driving, the needle shows location radially with respect to the station
          a. The needle points to the bearing TO the station
          b. The tail points to the radial of the VOR the aircraft is currently on/crossing

e. **Using the NDB**
   - Orientation
     a. The ADF needle points TO the station, regardless of heading or position
       1. RB indicated thus is the angular relationship between heading and the station
       a. Measured clockwise from the nose of the aircraft
     b. Visualize the ADF dial in terms of the longitudinal axis
       1. When the needle points to 0°, the nose points directly to the station
       2. With the pointer on 210°, the station is 30° to the left of the tail
       3. With the pointed on 090°, the station is off the right wingtip
       4. The RB itself does not indicate position
         a. The RB must be related to aircraft heading to determine direction TO/FROM

e. **Global Position System (GPS)**
   i. Satellite based navigation systems include
a. GPS (Global Positioning System), WAAS (Wide Area Augmentation System), LASS (Local...)

ii. GPS

a. The GPS system is composed of 3 major elements

- The Space Segment
  a. Composed of a constellation of 24 satellites approx 11,000 NM above the earth
    1. Arranged so at anytime, 5 are in view to any receiver (4 are necessary for operation)
    2. Each satellite orbits the Earth in approx 12 hrs
    3. Equipped with highly stable atomic clocks and transmit a unique code/nav message
  b. The satellites broadcast in the UHF range (so they are virtually unaffected by weather)
    1. Although they are subjected to line-of-sight references
      a. Must be above the horizon (as seen by the antenna) to be usable for navigation

- The Control Segment
  a. Consists of a master control station, 5 monitoring stations, and 3 ground antennas
  b. The monitoring stations and ground antennas are distributed around the earth to allow continual monitoring and communications with satellites
    1. Nav message updates are uplinked as satellites pass over the ground antennas

- The User Segment
  a. Consists of all components associated with the GPS receiver
    1. Range from portable, hand-held receivers to permanently installed
  b. The receiver utilizes the signals from the satellites to provide:
    1. Positioning, velocity, and precise timing to the user

b. Solving for Location

- The receiver utilizes the signals of at least 4 of the best positioned satellites to yield a 3D fix
  a. 3D - Latitude, longitude, and altitude
  b. Using distance/position info from the satellite, the receiver calculates its location

c. Navigating

- VFR navigation with GPS can be as simple as selecting a destination and tracking the course
- GPS Tracking
  a. Course deviation is linear, there is no increase in sensitivity closer to waypoints
- It can be very tempting to rely exclusively on GPS, but never rely on one means of navigation

Conclusion:
Brief review of the main points