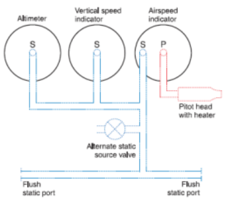
II.B. Aircraft Flight Instruments and Navigation Equipment

References: 14 CFR Parts 61, 91, Instrument Flying Handbook (FAA-H-8083-15), AIM

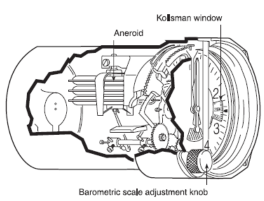
KNOWLEDGE

The applicant demonstrates understanding of:

1. **The General Operation of Flight Instruments:**
   A. Pitot-Static System
      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



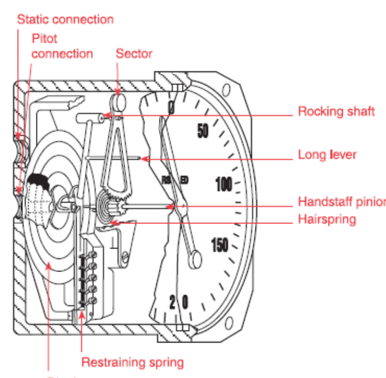
            - The sensitive element is a stack of evacuated, corrugated bronze aneroid capsules
               a Air pressure tries to compress them, while natural springiness tries to expand them
               b This results in their thickness changing as their air pressure changes
                  1. The change 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
                  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. 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 altitude and putting the aircraft in a potentially dangerous position (lower than the altimeter indicates)
    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/Electric Instruments
    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 axes

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
    - Vacuum Systems
        - a The ACS has separated Vacuum systems from the Gyroscopic Systems, the information can be found below in Part E of this section.

ii. Attitude Indicator

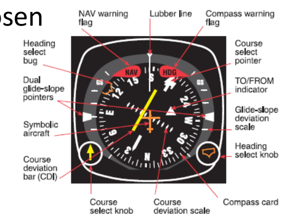
a. Principle of Operation
    - Its operating mechanism is a small brass wheel with a vertical spin axis
        - a It is spun by either a stream of air on buckets cut into its periphery or an electric motor
    - Mounted in a double gimbal which allows the aircraft to pitch and roll about the gyro
        - 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
      - It has a pushbutton means of selecting either slaved or free gyro mode
      - The RMI 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
      - 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

c. Turn Coordinator
- Similar to the Turn and Slip Indicator, but its gimbal frame is angled upward about 30° from the longitudinal axis of the airplane
  - a. This allows it to sense both roll and yaw (not just yaw like the T&S Indicator)
- The inclinometer is the same, and called a coordination ball
  - a. 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. Electrical Systems, Electronic Flight Instrument Displays (PFD, MFD), Transponder

i. Electrical Systems

a. Advances in technology have brought about changes in the instrumentation found in all types of aircraft; for example, Electronic Flight Displays (EFDs)
- EFDs include flight displays such as the Primary Flight Display (PFD) and Multi-Function Display (MFD)
- This has changed the information available to the pilot as well as how the information is displayed
  - a. In addition to improvement in system reliability, EFDs have decreased the overall cost of equipping aircraft with state-of-the-art instrumentation

ii. PFD and MFD

a. PFD
- Provide increased situational awareness to the pilot by replacing the traditional 6 instruments used for instrument flight with an easy-to-scan digital display that provides the horizon, airspeed, altitude, vertical speed, trend, trim, rate of turn, and other relevant indications
  - a. In essence, it provides more useful information in an easier to use format

b. MFD
- Provides the display of information in addition to the primary flight information shown on the PFD
  - a. Information such as moving maps, approach charts, terrain awareness, weather depiction, and more can be depicted on the MFD
  - b. For redundancy, both the PFD and MFD can display all critical information presented by the other screen, providing a redundancy not found in past general aviation flight decks

c. The more familiar you are with your particular system, the safer and more situationally aware you can become. Take the time to thoroughly learn your system.

iii. Transponder

a. ATC radar facilities have both primary and secondary radar
- Primary radar returns are the energy returned from an aircraft's metallic structure
  - a. Limitations: Only reports azimuth and range (no altitude), not great with small, composite aircraft, and limited by terrain and precipitation
- Secondary Radar solves a lot of these limitations
  - a. Secondary radar depends on a transponder in the aircraft to respond to interrogations from a ground station
    1. The pilot inputs a 4-digit code assigned by ATC into the transponder
    2. Depending on the type of transponder, and the type of interrogation, the transponder sends back an identification code as well as altitude

    a. Mode A: Sometimes referred to as Mode3/A, it responds to an interrogation signal with the input transponder code
    b. Mode C: Equipped with an altitude encoder and altimeter. ATC will see the flight altitude on their radar screen
        i. Primary returns only display range and bearing from the radar antenna, when the transponder's function switch is in the ALT position, the aircraft's pressure altitude is sent to the controller (changing the altimeter setting has no effect on the altitude read by the controller)
    c. Mode S: A platform for a variety of other applications, such as Traffic Information Service (TIS), Graphic Weather Service, and Automatic Dependent Surveillance-Broadcast (ADS-B). It provides improved surveillance quality, discrete aircraft addressing function and digital capability

b. VFR Transponder Operation
    - Unless otherwise instructed by an ATC facility, squawk 1200 when operating VFR
        a Flight following is the most common example as to when you would squawk something other than 1200 (more info below in part 5. Radar Assistance)
    - If equipped, Mode C should be activated
        a Unless ATC requests otherwise or the equipment has not been tested as required in FAR 91.217

c. Mode C Transponder Requirements
    - A mode C transponder is required:
        a At or above 10,000' MSL over the contiguous 48 states (and DC), excluding the airspace below 2,500' AGL
        b Within 30 nm of a Class B airspace primary airport, below 10,000' MSL
        c Within and above all Class C airspace, up to 10,000' MSL
        d Within 10 nm of certain designated airports, excluding airspace outside Class D and below 1,200' AGL

d. Emergency Transponder Codes
    - 7500 – Hijack
    - 7600 – Lost Communications
    - 7700 – Emergency
    - When making a code change, avoid inadvertently selecting 7500, 7600, or 7700 to avoid causing momentary false alarms at ground facilities

e. Transponder Related Terms
    - These can be found in the AIM, Chapter 4-1-20 Part h

D. Magnetic Compass

i. Operation

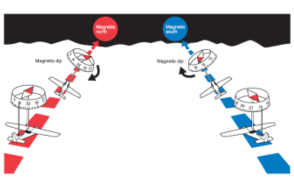
a. Two small magnets attached to a metal float sealed inside a bowl of clear compass fluid

b. A card is wrapped around the float and visible from the outside with a lubber line
    - 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
    - The buoyancy of the float takes most of the weight off the pivot
    - The jewel and pivot type mounting allow the float to rotate and tilt up to approximately 18°

d. The magnets align with the Earth's magnetic field and direction is read opposite the lubber line
   - 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
   - Caused by the difference in the locations of the magnetic and geographic north pole
   - The north magnetic pole is not collocated with the geographic north pole
     a The difference between true and magnetic directions
   - Isogonic Lines: Lines drawn across aeronautical charts connecting points have the same magnetic variation
   - 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
   - Caused by local magnetic fields within the aircraft; different on each heading
   - The magnets in a compass align with any magnetic field
     a Local magnets caused by electrical currents will conflict with the Earth's field
   - Deviation varies by heading and is shown on a compass correction card
  c. Finding the Compass Course
   - True Course ± Variation = Magnetic Course ± Deviation = Compass Course
   - Remember: East is Least, West is Best
     a Subtract variation from true course; Add variation to true course
  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:

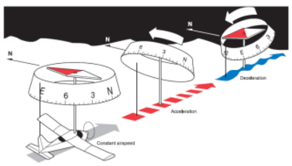


       1. The aircraft banking to the right and the compass card tilting to the right
       2. Then, the vertical component pulls the N seeking end of the compass to the right
          a. The float rotates, causing the card to rotate toward the W (opposite the turn)
     c The same happens when turning to 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; float rotates to 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

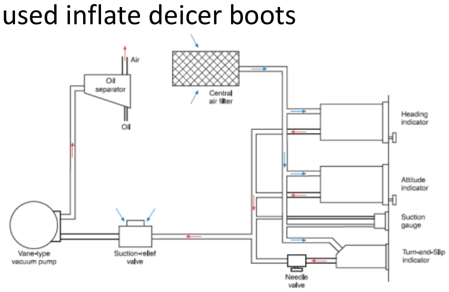
- Acceleration Error



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

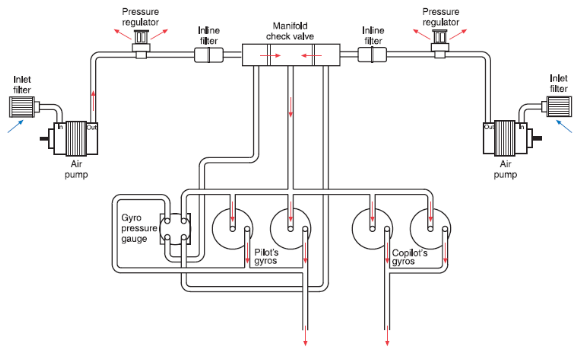
e. Oscillation Error
   - Oscillation is a combination of all the other errors
     a It results in the compass card swinging back and forth around the heading being flown
   - When setting the HI to the MC, use the average indication

E. Vacuum Systems
   i. Wet-Type Pump 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



   ii. Dry-Air Pump Systems
      a. At high altitudes, more air is needed in the instruments as the air is less dense
         - 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
   iii. 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



2. The General Characteristics of Navigation Instruments

A. NAVAIDs

B. VOR (Very High Frequency Omni-Directional Range)

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 – Military tactical air navigations (TACAN) equipment is installed with VOR

- DME is always an integral part of a VORTAC

ii. What is it?

a. Omni means all

- An *omni*directional 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

- A radial is defined as a line of magnetic bearing extending outward from the VOR station
- 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

- 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:

- T (Terminal); L (Low Altitude); H (High Altitude)

iii. VOR Checks

a. The best assurance of maintaining an accurate VOR receiver is periodic checks and calibrations

- Not a regulation for VFR flight

b. Checks (checkpoints are listed in the A/FD)

Class	Altitudes	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

- FAA VOR Test Facility (VOT)
- Certified Airborne Checkpoints
- Certified Ground Checkpoints located on airport surfaces
- 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

- Station can be identified by its Morse code ID or a voice stating the name and VOR
- If the VOR is out of service, the coded identification is removed and not transmitted
    - a It should not be used for navigation
- 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

- The ground transmitter and the receiver
    - a The 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 (Omni Bearing Selector), referred to as the course selector
            b. A CDI (Course Deviation Indicator) Needle
            c. A To/From Indicator
- 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 determine
- When the OBS is rotated, the CDI moves showing the radial relative to the airplane
- 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 MON (Minimum Operating Network)

a. National Airspace System is transitioning to performance-based navigation (PBN)

- Number of VORs is being reduced (going from 896 to 590 by 2030)
- Two new, larger service volumes will enable near continuous navigation above 5,000' AGL

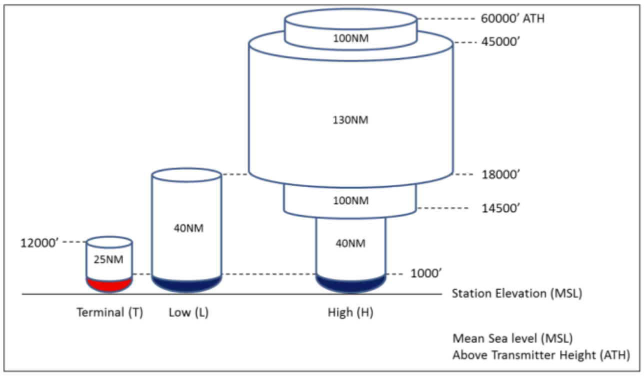
b. Designed to enable aircraft, having lost GPS, to revert to conventional navigation procedures

c. New Service Volumes

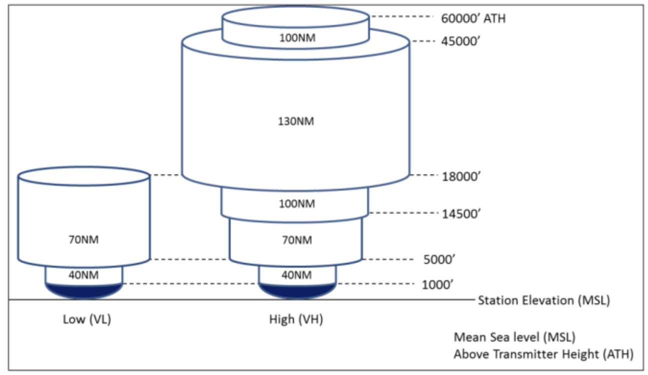
- Low: 70 nm from 5,000' to 18,000'

- High: 70 nm from 5,000’ to 14,500’

LEGACY SERVICE VOLUMES



NEW SERVICE VOLUMES



vi. 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

C. DME
i. Function
   a. When with a VOR, DME can determine position, including bearing and distance TO/FROM the station
      - Used for determining the distance from a ground DME transmitter
      - 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 ground speed 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 of the desired station

- On/Off/Volume: Can be used to identify the DME (Morse code plays 1x for every 3-4x VOR)
- Mode Switch: Cycles between Distance, ground speed 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

D. ILS and Marker Beacon Receiver/Indications

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

- 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 approximately 3° from the approach end of an instrument runway to provide vertical guidance for final approach
- Equipment is housed in a building approximately 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 middle marker at about 200' and the outer marker 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 glide path (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 glide path
  - The Middle Marker (MM)
    - a Approximately 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

iii. 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
- BCM (Back Course Marker)
    - a High pitched tone
    - b Two dots at a rate of 72 to 75 two dot combinations per minute
    - c White marker beacon light
- Sensitivity: can be selected as high or low
    - a Low provides the sharpest indication of position and should be used on approach

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: glide slope facilities inherently produce additional courses at higher vertical angles

vii. If the approach is made at the altitudes shown on the charts, they won't be encountered

E. RNAV
i. Includes VOR/DME, GPS and Inertial Navigation Systems (INS)
a. Capable of computing aircraft position, actual track, ground speed, and presenting it to the pilot

ii. VOR/DME
a. The system compares the aircraft's location to VORTAC or VOR/DME stations to determine location and guidance information

iii. GPS
a. The GPS system is composed of 3 major elements
- The Space Segment
    - a Composed of a constellation of 24 satellites approximately 11,000 NM above the earth
        1. Arranged so at any time, 5 are in view to any receiver (4 are necessary for operation)
        2. Each satellite orbits the Earth in approximately 12 hours

        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

d. Receiver Autonomous Integrity Monitoring (RAIM)
- RAIM is the GPS receiver's ability to verify the integrity (usability) of the signals received from the GPS constellation
    - a Without RAIM capability, the pilot has no assurance of the accuracy of the GPS position
- RAIM needs a minimum of 5 satellites in view, or 4 satellites and a barometric altimeter baro-aiding to detect an integrity anomaly
    - a Some receivers have the ability to isolate and remove a corrupt signal if 6 satellites, (or 5 with baro-aiding) are in view
- Generally, there are 2 types of RAIM messages
    - a One indicates that there are not enough satellites in view to provide RAIM
    - b Another indicates that the RAIM has detected a potential error that exceeds the limit required for the current phase of flight
- Aircraft using GPS navigation equipment under IFR must be equipped with an approved and operation alternate means of navigation appropriate to the route of

flight, but active monitoring of the alternative navigation equipment is not required if the GPS receiver uses RAIM for integrity monitoring
        a Active monitoring of navigation equipment is required when the RAIM capability of the GPS equipment is lost though
        b In situations where the loss of RAIM capability is predicted to occur, the flight must rely on other approved equipment, delay departure, or cancel the flight

e. GPS Substitution
    - GPS systems, certified for IFR en route and terminal operations, may be used as a substitute for ADF and DME receivers when conducting the following operations within the NAS:
        a Determining the aircraft position over a DME fix
        b Flying a DME arc
        c Navigation TO/FROM an NDB/Compass Locator
        d Determining the aircraft position over an NDB/compass locator
        e Determining the aircraft position over a fix defined by an NDB/Compass Locator bearing crossing a VOR/LOC course
        f Holding over an NDB/Compass Locator

iv. INS
    a. A system that navigates precisely without any input from outside the aircraft
        - The INS is initialized by the pilot, who enters the exact location of the aircraft into the system before flight
    b. Components
        - Accelerometer – To measure acceleration, which when integrated with time, gives velocity
        - Gyros – To measure direction
    c. Errors
        - The principal error is degradation of position with time
            a Accelerometers and gyros are subject to very small errors, and as time passes the errors accumulate
            b The best systems display errors of 0.1 to 0.4 NM after 4 to 6 hours, less expensive systems show errors of 1 to 2 NM per hour.

F. WAAS
    i. Satellite based augmentation system that improves GPS signals for use in precision approaches
        a. Designed to improve the accuracy, integrity, and availability of GPS signals
            - The integrity is improved through real-time monitoring of the satellites, the accuracy is improved by providing corrections to the satellites to reduce errors. As a result, performance improvement is sufficient to enable approach procedures with GPS/WAAS glidepaths
        b. Basically, it augments the basic GPS satellite constellation with additional ground stations/enhanced info transmitted from geostationary satellites
        c. Worst case, WAAS accuracy is approximately 25 feet 95% of the time
    ii. Approach Capabilities
        a. WAAS receivers support all basic GPS approach functions and provide additional capabilities with the key benefit to generate an electronic glidepath, independent of ground equipment or barometric aiding

- This eliminates several problems, such as cold temperature effects, incorrect altimeter setting, or lack of a local altimeter source, and allows approach procedures to be built without the cost of installing ground stations at each airport.

b. A new class of approach procedures, which provide vertical guidance requirements for precision approaches, has been developed. These procedures are called Approach with Vertical Guidance (APV) and include approaches such as LNAV/VNAV procedures presently being flown

G. Flight Management System (FMS)

i. An FMS is not a navigation system in itself, rather it is a system that automates the tasks of managing the onboard navigation systems

a. It is an interface between the flight crew and flight deck system, or a computer with a large database of airport and NAVAID locations and associated data, aircraft performance data, airways, intersections, departure procedures, and STARs.

b. An FMS can quickly define a desired route, perform flight plan computations, and display the total picture of the programmed flight route to the crew.

ii. The FMS can also control the various NAVAIDs onboard the aircraft and receive navigational data from them

a. VOR, DME, LOC, etc.

iii. Capabilities of the FMS will vary based on the system installed in the aircraft being flown

H. Autopilot

i. General Characteristics

a. Autopilots can control the 3 axes (pitch, roll, yaw) of an aircraft through various means, including electrical, hydraulic, or digital systems

- Most general aviation autopilots control pitch and roll

b. Autopilots also function using different methods: Position, or Rate Based Systems

- In order to control the aircraft, the system must be provided with constant information on the actual attitude of the aircraft. This is accomplished by the use of several different types of gyroscopic sensors
  - a Some indicate the aircraft's attitude in the form of position in relation to the horizon, while others indicate rate (position change over time)
- Position Based
  - a The attitude gyro senses the degree of difference from a position such as wings level, a change in pitch or a heading change
- Rate Based
  - a These systems use the turn and bank sensor for the autopilot system
    1. The autopilot uses rate information on two of the aircraft's three axes (vertical and longitudinal axes, or heading and roll)
- Other autopilot systems use a combination of position and rate-based information, while newer systems are digital

ii. Common Failure Modes

a. Autopilots can fail in different ways depending on the system installed, it's operating method and the information it receives from various systems in the aircraft

- Many simple autopilots can fail in either than heading/roll mode or the altitude/pitch mode

b. In the case of more current autopilots, such as those connected to a G1000 or something similar, the autopilot may fail due to failure of another system, for example:

- If the AHRS (attitude heading reference system) fails the failure results in the loss of all heading and attitude indications on the PFD, in addition all modes of the autopilot, except for roll and altitude hold are lost
- If the AHRS and ADC (air data computer) fail, there are no indications of the aircraft's attitude, and the autopilot can operate in roll mode (simply as a wings leveler)
    - a The autopilot is equipped with inputs from a turn coordinator installed behind the MFD. This turn coordinator is intended solely for the use of the autopilot to facilitate the roll mode (wings leveler)
        1. This protection is always available, irrespective of the ADC/AHRS failures, barring a failure of the turn coordinator itself

c. Be familiar with the common failure modes associated with your aircraft and autopilot system

RISK MANAGEMENT

The applicant demonstrates the ability to identify, assess, and mitigate risks, encompassing:

1. Failure to Monitor and Manage Automated Systems

A. Understand the Platform
- i. Read and understand the system's manuals and adhere to the AFM/POH procedures

B. Automation System Requirements:
- i. Familiarity
    - a. Familiarity with all equipment is critical in optimizing safety and efficiency
    - b. Being unfamiliar adds to the pilot's workload and may contribute to a loss of situational awareness
- ii. Respect for Onboard Systems
    - a. A thorough understanding is essential to gaining the benefits the system can offer
        - Understanding leads to respect
- iii. Reinforcement of Onboard Suites
    - a. Practice what you've learned to gain experience; reinforcement yields dividends in the use of automation and reduces workload
- iv. Getting Beyond Rote Workmanship
    - a. The desire is to become competent and know what to do without having to think about what you need to do next
    - b. Operating with competency and comprehension benefits a pilot when situations become more diverse and tasks increase
- v. Understand the Platform
    - a. Review and understand the different ways systems are used in a particular aircraft

C. Turn it off, if necessary
- i. If the automation isn't doing what you intend in flight, turn it off and reset it, or leave it off and fly the plane
- ii. A failure to monitor and manage the automation can result in the aircraft flying in a different direction than intended without the pilot's knowledge
    - a. For example, if you intend to fly a GPS or VOR course but the automation remains in a heading or roll mode, or a climb to an incorrect altitude

D. If the automation becomes a distraction, especially in the way of flying the aircraft competently and communicating with ATC, either turn it off or ensure it is operating properly

2. The Difference between Approved and Non-Approved Navigation Devices

A. Approved navigation devices have to comply with specific requirements outlined by the FAA.
   i. For example, equipment approved in accordance with TSO C-115a, visual flight rules, and hand-held GPS systems do not meet the requirements of TSO C-129 and are not authorized for IFR navigation, instrument approaches, or as a principal instrument flight reference
   ii. During IFR operations, equipment approved under TSO C-115a can only be used as an aid to situational awareness

3. Common Failure Modes of Flight and Navigation Instruments

A. Altimeter
   i. The altimeter is checked by setting the barometric scale to the local altimeter setting. If the altimeter is more than 75' from the surveyed elevation, the instrument should be recalibrated.
   ii. Weather Errors (not a failure, just an inherent error in the altimeter)
      a. When the aircraft is flying in air that is warmer than standard, the air is less dense and the pressure levels are farther apart
         - If the aircraft is flying at 5,000', the pressure level for that altitude is higher in warmer air than it would be at standard temperature, and the aircraft is higher than if the air were cooler
      b. If the aircraft is flying in air that is colder than standard, it is denser and the pressure levels are more compressed
         - When the aircraft is flying at 5,000', it's true altitude is lower than it would be if the air were warmer
   iii. If the static port becomes blocked the trapped static pressure causes the altimeter to freeze at the altitude where the blockage occurred
   iv. Digital Displays (like a G1000)
      a. If there is a failure of the pitot-static system, most systems will indicate the failure by removing the data and showing a red x over the failed instrument(s)

B. Vertical Speed Indicator
   i. During the preflight, if the indicator shows anything other than zero, (for example, on the ground the indicator indicates a 100-fpm descent) use that as zero
      a. In this example, an indication of 0 fpm would equate to a 100-fpm climb
      b. Reference the flight manual for more information, but if the deviation is excessive get the instrument checked or repaired if necessary
   ii. Blocked Static System
      a. In the case of a blocked static system, the VSI produces a continuous zero indication
   iii. Digital Displays (like a G1000)
      a. If there is a failure of the pitot-static system, most systems will indicate the failure by removing the data and showing a red x over the failed instrument(s)

C. Airspeed Indicator
   i. The airspeed indicator is often checked during the takeoff roll to ensure proper operation
      a. Reject the takeoff in the case airspeed does not indicate or does not operate properly
   ii. Blocked Pitot-Static System
      a. If the pitot system becomes blocked, dynamic pressure cannot enter the system and the airspeed indicator no longer operates
         - If the drain hole is open, the pressure drains and airspeed decreases to zero

- If the drain hole is also blocked, the airspeed indicator will operate similar to an altimeter
  - a As altitude increases, the airspeed will increase and as altitude decreases, the airspeed will decrease

b. If the static system is blocked, but not the pitot port, the airspeed indicator continues to operate but is not accurate
- When the aircraft is operated above the altitude at which the blockage occurred, the airspeed indicates lower than the actual airspeed since the trapped pressure is higher than normal for the altitude
- When the aircraft is operated below the altitude at which the blockage occurred, the airspeed indicates higher than the actual airspeed since the trapped pressure is lower than normal for the altitude

iii. Digital Displays (like a G1000)

a. If there is a failure of the pitot-static system, most systems will indicate the failure by removing the data and showing a red x over the failed instrument(s)

D. Attitude Indicator

i. Conventional attitude indicators are quite reliable but can fail over time

a. Failure can be indicated on the ground if the indicator does not rise to its vertical position in the display
- This can take as long as 5 minutes, but is usually done within 2 or 3 minutes
- If during taxi out the attitude indicator fails to rise or respond properly to turns, consider it failed and have it serviced

b. Additionally, some attitude indicators can tumble
- Older instruments are limited in the amount of pitch or roll they can tolerate. When a limit is reached, the gyro housing contacts the gimbals, applying such a precessing force that the indicator tumbles providing incorrect attitude indications

ii. Digital Displays (like a G1000)

a. If there is a failure of the AHRS, most systems will indicate the failure by removing the data and showing a red x over the failed instrument(s)

E. Heading Indicator

i. Gyro heading indicators (with the exception of slaved gyro indicators) are not North seeking and therefore must be manually set to the appropriate heading by reference to a magnetic compass

a. The earth constantly rotates at 15 degrees per hour while the gyro is maintaining a position relative to space, thus causing an apparent drift in the displayed heading. When using these instruments, it is standard practice to reset the heading on the indicator to match the compass

b. Considerably more than 15 degrees per hour can be considered a failure of the instrument

c. Problems with the internal mechanisms can result in the heading indicator rotating uncontrollably
- Have the indicator repaired, and if in flight use the magnetic compass to navigate

d. The heading indicator should be checked for proper operation on the ground. The heading should change with turns and match the compass (within reason)

ii. Digital Displays (like a G1000)

a. If there is a failure of the AHRS, most systems will indicate the failure by removing the data and showing a red x over the failed instrument(s)

F. Turn and Slip Indicator
    i. The turn and slip indicator should also be check during taxi out for correct operation
        a. Failure of the internal mechanisms can result in incorrect information being displayed
        b. The ball has no internal mechanism, but should swing in the opposite direction of any turns during taxi
    ii. Digital Displays (like a G1000)
        a. If there is a failure of the AHRS, most systems will indicate the failure by removing the data and showing a red x over the failed instrument(s)

G. Navigation Instruments
    i. The majority of navigation instruments have some sort of flag or indication that the signal is unusable or unreliable
        a. For example, many VORs have an "OFF" flag which retracts from view when signal strength is sufficient for reliable instrument indications
        b. Alternately, insufficient signal strength can be indicated by a blank indication or OFF in the TO/FROM window
        c. An off signal does not necessarily imply the signal strength is the problem, it may be a defective device that cannot pick up the signal
    ii. Other, older instruments may not have an OFF indication and simply won't indicate in the case that there is a problem
    iii. Be sure to use the flight manual to understand what indications to expect in the case of an issue with the navigation equipment
    iv. Digital Displays (like a G1000)
        a. In the case of a failure on a digital display, often the pilot will see a red X indicating failure of the system

4. The Limitations of Electronic Flight Bags (EFBs)

A. Dependency
    i. When a pilot becomes familiar and comfortable with the new electronic displays, he or she also tends to become more reliant on the system. The system then becomes a primary source of navigation and data acquisition instead of the supplementary source of data as initially intended
        a. Complete reliance becomes a problem during failure if the pilot has relied on the display for navigational information and situational awareness
        b. Follow the flight on physical charts (sectionals, approach plates, STARs, DPs, etc.) while monitoring the electronic flight bag information
            - Don't lose the information and/or your situational awareness if you lose the display

B. Database Currency
    i. As with paper publications, EFB information needs to be updated on the same cycle.
    ii. Improper maintenance, the inability to connect to the internet, or a neglect of the database's currency can leave the pilot without a valid database, rendering the EFB unfit for use

C. Power
    i. If the battery runs out, the information is gone until power can be restored.
    ii. Ensure the EFB is properly charged prior to flight

D. Backup Plan
    i. If the EFB is damaged, fails, loses power, etc. the pilot has no reference to the charts, maps, and other information contained in the EFB
    ii. Monitor the EFB and back it up with physical charts, approach plates, STARs, DPs, etc.

5. Failure to Ensure Currency of Navigation Databases

A. Outdated information puts the pilot and other aircraft/people at risk. Do not use outdated publications or databases
    i. The information needs to be current to produce accurate information regarding procedures, NAVAIDS, waypoints, etc.
    ii. For example, arrival and departure procedures can change, sometimes drastically. A pilot flying with an outdated procedure could quickly and unknowingly create a hazardous situation or, worst case, mid-air collision
B. Always update your database
    i. If it's not updated, the aircraft is not current to fly
        a. If you need to fly, get current paper charts and use the database as a backup for situational awareness

SKILLS

The applicant demonstrates the ability to:

1. Operate and manage installed instruments and navigation equipment.