2025-05-19 - Instruments Lecture 2

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> Location: [Insert Location]
> [Insert Title]
> `gyroscopic instruments` `magnetic compass` `flight instrumentation`

Theme

This lecture provides an in-depth overview of aircraft gyroscopic instruments, magnetic compass operation, and related flight instrumentation. Topics include the principles, limitations, and errors of gyroscopes, compass deviation and variation, instrument checks, vacuum and electrical systems, EFIS, and alerting systems. Practical considerations, exam mnemonics, and study strategies for aviation students are also discussed.

Takeaways

1. Gyroscopic instruments in aircraft: degrees of freedom and axis orientation
2. Turn indicator vs. turn coordinator: differences and functions
3. Turn coordinator: gyroscope axis, gimbal tilt, and information provided
4. Precession in gyroscopes and its effect on instrument indication
5. Turn coordinator limitations: no pitch information
6. Electrical vs. suction-driven gyroscopic instruments
7. Suction system: components and operation
8. Instrument checks and maintenance indicators (red flag)
9. Taxi checks for turn coordinator (balance ball behavior)
10. Vacuum relief valve function in suction system

Highlights

- `"Simply what you have to do is you have to align these two yellow arrows with the magenta one. Simple as that."-- Speaker 2`
- `"It's really hard for manufacturers to design and construct the perfect instrument, which is not going to have any errors."-- Speaker 2`
- `"Accelerate north, decelerate south, in the northern hemisphere."-- Speaker 2`

- `"Undershoot North, overshoot South."-- Speaker 2`
- `"Anything can happen. You as a pilot, you should know that these arrows exist, because imagine you don't know that and you experience it for the first time in cockpit and you'll say, oh my god."-- Speaker 2`
- `"It's a warning means that the aircraft is telling me to quickly analyze what's happening and to do something, right? To take the appropriate action."-- Speaker 2`
- `"The power is in all of our actions."-- Speaker 5`

Chapters & Topics

Gyroscopic Instruments in Aircraft: Degrees of Freedom and Axis Orientation

> Gyroscopic instruments in aircraft can have different degrees of freedom and axis orientations depending on their type and function. The attitude indicator typically has two degrees of freedom, while the direction indicator may have only one. The axis orientation (vertical, horizontal, or tilted) is crucial for understanding the instrument's operation.

- **Keypoints**
  - Attitude indicator: two degrees of freedom, two indexes.
  - Direction indicator: one degree of freedom, rotates vertically.
  - Gyroscope axis can be vertical, horizontal, or tilted (e.g., 30 degrees in turn coordinator).
  - Type of indicator (direction, attitude, turn) determines axis and degrees of freedom.
- **Explanation**
  The lecture explains that not all gyroscopes in aircraft have two degrees of freedom. For example, the attitude indicator has two, but the direction indicator has only one. The axis orientation is also important: in the turn coordinator, the gimbal is tilted 30 degrees to the aircraft's longitudinal axis, while the spin axis remains horizontal.
- **Considerations**
- Know the type of axis and degrees of freedom for each gyroscopic instrument.
- Understand the difference between gimbal orientation and spin axis.

Turn Indicator vs. Turn Coordinator: Differences and Functions

> The turn indicator and turn coordinator are both gyroscopic instruments, but the turn coordinator is an evolution of the turn indicator, providing additional information such as the inclinator (balance ball) and bars indicating turn quality.

- **Keypoints**

  - Turn indicator shows only the quality of the turn.
  - Turn coordinator shows turn quality, balance (inclinator), and bar indications.
  - Turn coordinator's gimbal is tilted 30 degrees for more precise indication.
- **Explanation**
  The turn coordinator provides more information than the turn indicator, including whether the turn is balanced and the quality of the turn. The gimbal is tilted 30 degrees, as decided by engineers for optimal precision.
- **Considerations**
- Remember the additional features of the turn coordinator compared to the turn indicator.

Turn Coordinator: Gyroscope Axis, Gimbal Tilt, and Information Provided

> The turn coordinator's gyroscope has a horizontal spin axis and a gimbal tilted 30 degrees to the aircraft's longitudinal axis. This configuration allows the instrument to provide precise turn and balance information.

- **Keypoints**
  - Spin axis is horizontal (parallel to the earth).
  - Gimbal is tilted 30 degrees to the aircraft's longitudinal axis.
  - Provides turn quality, balance, and bar indications.
- **Explanation**
  The gimbal tilt of 30 degrees was chosen by engineers for optimal precision. The spin axis remains horizontal, ensuring consistent direction. The instrument is sensitive to yaw only, not pitch.
- **Considerations**
- Do not confuse gimbal orientation with spin axis orientation.
- Remember the 30-degree tilt for the turn coordinator.

Precession in Gyroscopes and Its Effect on Instrument Indication

> Gyroscopic precession causes the force applied to the gyroscope to act 90 degrees later in the direction of rotation, affecting the instrument's output and indication.

- **Keypoints**
  - Precession causes the gyroscope's response to be tilted relative to the applied force.
  - Instrument output is based on this precessional effect.
- **Explanation**
  When yaw occurs, the precession of the gyroscope results in a force acting 90 degrees to the gyroscope, leading to the instrument's indication.
- **Considerations**

- Understand how precession affects gyroscopic instrument readings.

Turn Coordinator Limitations: No Pitch Information

> The turn coordinator does not provide pitch information; it is sensitive only to yaw (left or right movement).

- **Keypoints**
  - Turn coordinator does not indicate pitch.
  - Exam questions may ask about this limitation.
- **Explanation**
  The instructor emphasizes that the turn coordinator only provides information about yaw and roll, not pitch. This is a common exam question.
- **Considerations**
- Remember that turn coordinator does not provide pitch information.

Electrical vs. Suction-Driven Gyroscopic Instruments

> Gyroscopic instruments can be powered by either electrical systems or suction (vacuum) systems. Electrical failure leads to loss of gyroscope speed and accuracy, while suction systems are common in older aircraft.

- **Keypoints**
  - Turn coordinator is typically electrically driven.
  - Loss of electrical power reduces gyroscope speed and accuracy.
  - Suction systems use engine-driven pumps to power gyroscopes in older aircraft.
- **Explanation**
  If electrical power fails, the gyroscope slows down and eventually stops, leading to inaccurate or no indication. Suction systems are used in aircraft like Cessna or Piper, where the engine drives a pump to create vacuum for the gyroscopes.
- **Considerations**
- Check for red flag indicators to confirm instrument operation.
- Understand the difference between electrical and suction-driven systems.
- **Special Circumstances**
- If encountering electrical failure, expect loss of gyroscopic instrument accuracy and eventual failure of indication.

Suction System: Components and Operation

> The suction (vacuum) system uses engine-driven pumps to create vacuum, powering non-electrical gyroscopic instruments such as the heading indicator and attitude indicator. The system includes filters, gauges, relief valves, and pumps.

- **Keypoints**
  - Vacuum air filter cleans incoming air.
  - Clean air is routed to attitude indicator, heading indicator, and suction gauge.
  - Suction gauge shows vacuum level; low vacuum reduces accuracy.
  - Vacuum relief valve releases excess air if vacuum is too high.
  - Vacuum pump expels air outside the system.
- **Explanation**
  The system starts with air entering through a vacuum air filter, then passing through the instruments and gauge. The vacuum relief valve ensures the system does not become over-pressurized, and the pump maintains airflow.
- **Considerations**
- Monitor suction gauge to ensure adequate vacuum.
- Understand the flow of air through the system and the function of each component.
- **Special Circumstances**
- If vacuum is too low, instrument accuracy will drop.
- If vacuum is too high, the relief valve will open to release excess air.

Instrument Checks and Maintenance Indicators (Red Flag)

> Gyroscopic instruments have indicators (such as a red flag) to show if they are functioning properly. If the red flag is visible, maintenance is required.

- **Keypoints**
  - Red flag indicates instrument malfunction.
  - No red flag at engine start means instrument is working.
  - Maintenance is required if the red flag appears.
- **Explanation**
  At engine start, check for the absence of the red flag to confirm the instrument is operational. If the flag appears, report for maintenance.
- **Considerations**
- Always check for red flag indicators before flight.
- **Special Circumstances**
- If red flag is present, do not rely on the instrument and seek maintenance.

Taxi Checks for Turn Coordinator (Balance Ball Behavior)

> During taxi, the turn coordinator’s balance ball should move to the opposite side of the turn: right when turning left, left when turning right. This confirms proper instrument function.

- **Keypoints**

- When turning left on the ground, the ball moves to the right.
    - When turning right, the ball moves to the left.
    - Verbal confirmation is required for instructor verification.
- **Explanation**
  During taxi, observe the balance ball's movement and confirm out loud to the instructor that the instrument is functioning correctly.
- **Considerations**
- Always perform and verbally confirm taxi checks for the turn coordinator.

Vacuum Relief Valve Function in Suction System

> The vacuum relief valve in the suction system automatically opens to release excess air if the vacuum level becomes too high, protecting the system and instruments.

- **Keypoints**
    - Prevents over-pressurization of the vacuum system.
    - Ensures safe operation of gyroscopic instruments.
- **Explanation**
  If too much air enters the system, the vacuum relief valve opens automatically to release it, maintaining proper vacuum levels.
- **Considerations**
- Understand the protective role of the vacuum relief valve.
- **Special Circumstances**
- If vacuum relief valve opens frequently, inspect the system for leaks or malfunctions.

Surgical Suction System Components and Operation

> The surgical suction system in aircraft consists of a pump driven by the engine, with redundancy provided by two pumps for safety. The vacuum pumps have a lifetime of 1000 flying hours and are automatically operated when the engine is started. The system is monitored using a suction gauge, which should indicate the needle in the green part to confirm sufficient vacuum.

- **Keypoints**
    - Two vacuum pumps are installed for redundancy.
    - Vacuum pumps have a lifetime of 1000 flying hours.
    - Operation is automatic upon engine start.
    - Suction gauge is used to check system status.
    - Some aircraft may lack a suction gauge.
- **Explanation**
  When the engine is started, the vacuum pump begins to operate automatically,

independent of pilot actions. The pilot checks the suction gauge to ensure the needle is in the green zone, indicating proper vacuum. If a pump fails, it is replaced with a new one as per its certificate.

- **Examples**
  > If a vacuum pump fails after 1000 flying hours, it is removed and replaced with a new one. The process is straightforward and does not require complex procedures.

  - Monitor the suction gauge during pre-flight checks.
  - If the gauge does not indicate sufficient vacuum, inspect the pump.
  - Remove the failed pump and install a new certified pump.
- **Considerations**
- Always check the suction gauge during pre-flight.
- Replace vacuum pumps after 1000 flying hours.
- Ensure redundancy by verifying both pumps are operational.
- **Special Circumstances**
- If the suction gauge does not move to the green zone after engine start, do not proceed with flight until the issue is resolved.

Vacuum System Failure and Relief Valve Issues

> Vacuum system failure can result in erroneous indications on flight instruments. A common cause is relief valve malfunction, leading to high pressure in the system and failure of the direction indicator.

- **Keypoints**
  - High pressure in the suction system may indicate relief valve failure.
  - Direction indicator may fail due to inability to relieve pressure.
  - No prior issues may be observed before failure.
- **Explanation**
  If the relief valve breaks, high pressure cannot be removed from the system, causing the direction indicator to fail. This is observed as a sudden loss of correct indication.
- **Examples**
  > During flight, the suction gauge shows very high pressure, and the direction indicator fails. Investigation reveals the relief valve is broken.

  - Monitor suction gauge for abnormal readings.
  - If high pressure is observed, suspect relief valve malfunction.
  - Direction indicator failure may follow due to system overpressure.
- **Considerations**
- Monitor suction gauge for abnormal high pressure.

- Be aware of relief valve as a potential failure point.
- **Special Circumstances**
- If the direction indicator fails in flight due to vacuum system issues, land as soon as possible.

Attitude Indicator (Artificial Horizon) Function and Structure

> The attitude indicator, also known as the artificial horizon, displays the pitch and roll of the aircraft. It uses a gyroscope with two degrees of freedom (pitch and roll) and is driven by the vacuum system. The spin axis is vertical, and the gyroscope rotates horizontally.

- **Keypoints**
  - Displays pitch (up/down) and roll (left/right) angles.
  - Two degrees of freedom provided by two gimbals.
  - Spin axis is vertical; gyroscope rotates horizontally.
  - Driven by vacuum system, not electrical.
  - Bank angle markings: 10, 20, 30, 45, 60 degrees.
- **Explanation**
  The gyroscope maintains its orientation in space, and the instrument displays changes in pitch and roll by moving the internal plate. The artificial horizon is marked with lines indicating specific bank angles, with 30 degrees typically being the maximum allowed in instrument flight.
- **Examples**
  > Each line on the attitude indicator represents a specific bank angle: first line is 10 degrees, then 20, 30, 45, and 60 degrees. The 30-degree line is emphasized as the maximum for instrument flight.

  - Use the markings to monitor and limit bank angles during flight.
  - Do not exceed 30 degrees in instrument flight as it is illegal.
- **Considerations**
- Do not exceed 30 degrees bank in instrument flight.
- Understand the meaning of each marking on the indicator.
- **Special Circumstances**
- If the attitude indicator shows a continuous pitch up of 10 degrees on the ground, do not proceed with flight.

Rate of One Turn and Calculation Formula

> The rate of one turn is indicated by aligning specific arrows on the instrument. The formula to calculate the rate of one turn is: 2 × airspeed divided by 10 plus air.

- **Keypoints**
  - Rate of one turn is indicated by aligning the upper arrow with the blue arrow.
  - Formula: 2 × airspeed / 10 + air.
  - Some aircraft lack rate of one turn triangles, requiring mental calculation.
- **Explanation**
  To achieve a rate of one turn, align the indicated arrows. If the instrument lacks these markers, calculate the rate using the provided formula based on airspeed.
- **Examples**
  > In the old Technon 2002 aircraft, there are no rate of one turn triangles, so the pilot must mentally calculate the rate using the formula.

  - Determine airspeed.
  - Apply the formula: 2 × airspeed / 10 + air.
  - Adjust turn rate accordingly.
- **Considerations**
- Know the formula for rate of one turn.
- Be prepared to calculate manually if instrument lacks markers.
- **Special Circumstances**
- If the instrument lacks rate of one turn triangles, perform mental calculation to ensure correct turn rate.

Flight Directors and Their Usage

> Flight directors provide visual guidance for following a flight plan. On some displays, magenta arrows indicate the desired path, and the pilot aligns the aircraft's yellow arrows with the magenta ones. Larger jets may use a cross-type flight director.

- **Keypoints**
  - Magenta arrows indicate desired flight path.
  - Align yellow arrows (aircraft) with magenta arrows (flight director).
  - Larger jets use cross-type flight directors.
- **Explanation**
  Load the flight plan and follow the magenta arrows by aligning the aircraft's indicators with them. On larger jets, follow the cross to maintain the correct path.
- **Examples**
  > Load the flight plan, turn on the flight directors, and align the yellow arrows with the magenta ones to follow the planned route.

  - Load flight plan into the system.
  - Turn on flight directors.
  - Align aircraft indicators with flight director guidance.

- **Considerations**
- Understand the display type of flight director in your aircraft.
- Follow the visual cues precisely for accurate navigation.

Attitude Indicator Serviceability Checks and Errors

> Serviceability checks involve observing the OFF flag and monitoring the indicator during taxi. Errors can occur if the gyro speed decreases, leading to reduced accuracy and sensitivity. If the suction drops to zero, the indicator may continue to function briefly due to gyro inertia but will eventually stop.

- **Keypoints**
  - OFF flag indicates electrical system-driven indicator.
  - Pitch changes during taxi are normal due to bumps.
  - Continuous pitch up of 10 degrees on ground indicates malfunction.
  - Gyro speed decrease reduces accuracy and sensitivity.
  - Gyro inertia allows brief continued operation after suction loss.
- **Explanation**
  During taxi, observe the indicator for normal pitch changes. If abnormal readings persist, do not fly. If suction is lost, the indicator may still work briefly but will stop as the gyro slows.
- **Examples**
  > Suction drops to zero, but the attitude indicator continues to work for a short time due to gyro inertia.

  - Monitor suction gauge.
  - If suction is lost, prepare to land as soon as possible.
  - Do not rely on the indicator for extended periods after suction loss.
- **Considerations**
- Check for OFF flag and abnormal pitch indications before flight.
- Do not fly if continuous abnormal readings are observed.
- **Special Circumstances**
- If suction is lost and the attitude indicator continues to work, land as soon as possible.

Direction Indicator Function and Operation

> The direction indicator uses a gyroscope with two degrees of freedom, rotating vertically with a horizontal spin axis. It senses yaw, not roll, and uses the principle of rigidity. The indicator must be checked during taxi to ensure correct operation.

- **Keypoints**

    - Two gimbals provide two degrees of freedom.
    - Gyroscope rotates vertically; spin axis is horizontal.
    - Senses yaw, not roll.
    - Uses rigidity principle.
    - Check operation during taxi: right turn increases heading (clockwise), left turn decreases heading (anticlockwise).
- **Explanation**
  During taxi, observe the direction indicator to ensure it responds correctly to turns. Align the indicator with the runway heading before takeoff. Adjust using the knob if necessary.
- **Examples**
  > Final course for runway 0-4 is 0-4-4 degrees. The direction indicator should read 0-4-4 when aligned on the runway.

    - Align aircraft on runway.
    - Check direction indicator reads 0-4-4.
    - If not, adjust using the knob.
- **Considerations**
- Always check direction indicator response during taxi.
- Align indicator with runway heading before takeoff.
- **Special Circumstances**
- If the direction indicator does not match runway heading, adjust using the knob before takeoff.

Gyroscope Errors: Gimbal Error and Drift Error

> Gyroscopes are subject to two main types of errors: Gimbal Error and Drift Error. Drift Error is further divided into Real Drift (Real Wonder) and Apparent Drift (Apparent Wonder).

- **Keypoints**
    - Gimbal Error: mechanical misalignment or restriction in gimbal movement.
    - Drift Error: deviation over time due to various factors.
    - Real Drift (Real Wonder): actual physical drift of the gyroscope.
    - Apparent Drift (Apparent Wonder): perceived drift due to Earth’s rotation or other factors.
- **Explanation**
  Understand the sources of error in gyroscopic instruments to interpret readings accurately and perform necessary corrections.
- **Considerations**
- Be aware of potential errors in gyroscopic instruments.

- Regularly check and calibrate instruments as needed.

Gimbal Error in Gyroscopes

> Gimbal error occurs when the movement of the gyroscope or the gimbal itself reaches its mechanical limit, preventing full rotation (not 360 degrees). This typically happens during high pitch or high bank maneuvers, causing the indicator to get stuck at a certain value (e.g., 70 or 80 degrees, depending on design).

- **Keypoints**
  - Gimbal error is due to mechanical limits of the gimbal.
  - Occurs during high pitch or bank angles.
  - Indicator may get stuck at 70 or 80 degrees.
  - Cannot rotate 360 degrees.
- **Explanation**
  When a pilot maneuvers the aircraft with high pitch or bank, the gimbal approaches its movement limit. This restricts the gyroscope's ability to indicate accurately, resulting in gimbal error.
- **Considerations**
- Be aware of gimbal limits during extreme maneuvers.
- Understand that indicator readings may be inaccurate when limits are reached.
- **Special Circumstances**
- If the gimbal reaches its movement limit during flight, the indicator may become stuck and not reflect actual aircraft attitude. Pilots should cross-check with other instruments.

Real Drift and Construction Imperfections

> Real drift is an error inherent in all gyroscopic instruments due to imperfections in their construction. This error is always present and cannot be completely eliminated.

- **Keypoints**
  - Real drift is caused by construction imperfections.
  - Always present in gyroscopic instruments.
  - Cannot be fully eliminated.
- **Explanation**
  Manufacturers cannot create a perfect gyroscope; thus, real drift is always present. This drift is due to small imperfections in the instrument's construction.
- **Considerations**
- Regular calibration and maintenance can minimize, but not eliminate, real drift.

Topple and Drift Errors in Gyroscopes

> There are two types of errors: topple and drift. Topple refers to movement away from the initial spin axis, while drift refers to movement of the gyroscope without changing the spin axis direction.

- **Keypoints**
  - Topple: movement away from initial spin axis.
  - Drift: movement of gyroscope, spin axis direction unchanged.
  - Both are types of gyroscope errors.
- **Explanation**
  Topple occurs when the axis of the gyroscope changes its position, while drift is when the gyroscope moves but the axis direction remains the same.
- **Considerations**
- Distinguish between topple and drift when diagnosing instrument errors.

Apparent Drift: Earth's Rotation and Transport Wander

> Apparent drift in gyroscopes is caused by two main factors: the rotation of the Earth and transport wander (movement of the aircraft over the Earth's surface). Earth's rotation causes the gyroscope's spin axis to want to topple, but this is compensated by a latitude nut. Transport wander occurs when the aircraft moves east-west or west-east, causing an apparent change in the gyroscope's orientation.

- **Keypoints**
  - Apparent drift has two causes: Earth's rotation and transport wander.
  - Earth's rotation causes the spin axis to want to topple.
  - Latitude nut compensates for Earth's rotation effect.
  - Transport wander occurs during east-west or west-east travel.
  - No error when only moving around longitude.
- **Explanation**
  When the aircraft moves due to Earth's rotation, the gyroscope's axis wants to change position (topple), but the latitude nut prevents this. When the aircraft travels east-west or west-east, the difference between the spin axis and north changes, causing transport drift.
- **Considerations**
- Mechanics must adjust the latitude nut based on aircraft location.
- Transport drift is more significant during long east-west flights.
- **Special Circumstances**
- If the latitude nut is not properly adjusted, gyroscope errors may increase, especially near the equator where Earth's rotation speed is higher.

Latitude Nut as a Compensating Device

> The latitude nut is a mechanical device installed in gyroscopic instruments to compensate for the toppling effect caused by Earth's rotation. It acts like a balance mass and can be adjusted left or right to maintain gyroscope accuracy.

- **Keypoints**
    - Latitude nut compensates for Earth's rotation-induced toppling.
    - Acts as a balance mass.
    - Adjustable by mechanics.
    - Prevents gyroscope axis from toppling.
- **Explanation**
  The latitude nut is adjusted depending on the aircraft's latitude to balance the gyroscope and prevent toppling due to Earth's rotation.
- **Considerations**
- Regular adjustment of the latitude nut is necessary, especially when flying at different latitudes.
- **Special Circumstances**
- If the latitude nut is not adjusted, gyroscope readings may become inaccurate, especially at locations closer to the equator.

Effect of Earth's Rotation on Gyroscope Errors

> The apparent toppling effect on gyroscopes due to Earth's rotation is maximum at the equator and zero at the poles. This is because the rotation speed is higher at the equator.

- **Keypoints**
    - Maximum apparent drift at the equator.
    - Zero apparent drift at the poles.
    - Latitude nut must work harder near the equator.
- **Explanation**
  In locations like Spain, which is close to the equator, the latitude nut must compensate more for Earth's rotation compared to locations near the poles.
- **Considerations**
- Be aware of location when adjusting gyroscope instruments.

Transport Wander (Transport Drift)

> Transport wander is an apparent error experienced by gyroscopes when the aircraft travels from west to east or east to west. It is caused by the change in the difference between the spin axis and north as the aircraft moves over the Earth's surface.

- **Keypoints**
    - Occurs during east-west or west-east travel.

    - No error when only moving around longitude.
    - Angle between spin axis and north changes with movement.
- **Explanation**
  As the aircraft moves east or west, the gyroscope's orientation relative to north changes, causing an apparent drift known as transport wander.
- **Considerations**
- Mechanics must adjust gyroscopes during long east-west flights.
- **Special Circumstances**
- If the gyroscope is not adjusted during long flights, transport drift error may accumulate.

Gyroscope Use in Aircraft and Helicopters

> Gyroscopes are used in both large jets and helicopters for attitude reference and stabilization. In helicopters, a rotating plastic device on top of the blade helps balance the propellers, though it may not be a true gyroscope.

- **Keypoints**
    - Gyroscopes are used in aircraft for attitude reference.
    - Helicopters use a balancing device on the blade, possibly not a true gyroscope.
    - Gyroscopes are also used in initial reference systems.
- **Explanation**
  Gyroscopes help determine aircraft attitude (pitch, bank, yaw) and are essential in both large and small aircraft, though the specific devices may differ.
- **Considerations**
- Understand the differences in gyroscope application between aircraft and helicopters.

Adjustment of Gyroscopes During Long Flights

> During long flights, especially those involving significant east-west travel, mechanics must adjust the gyroscope to prevent error accumulation due to transport drift.

- **Keypoints**
    - Gyroscopes require adjustment during long flights.
    - Prevents accumulation of transport drift error.
- **Explanation**
  If the gyroscope is not adjusted, errors may increase, affecting navigation and instrument accuracy.
- **Considerations**
- Regularly check and adjust gyroscopes during long flights.
- **Special Circumstances**

- If gyroscope adjustment is neglected, significant errors may develop, especially on intercontinental flights.

Principle and Construction of the Magnetic Compass

> The magnetic compass operates solely on the Earth's magnetic field. It consists of suspended magnets attached to a compass card, which is annotated with North, East, South, and West, and graduated in degrees. The compass card is shaped like an upturned cup and mounted on a pin to minimize friction and remain horizontal. The case is filled with kerosene or another liquid to reduce oscillation caused by aircraft movement.

- **Keypoints**
  - Compass card annotated with cardinal directions and degrees
  - Suspended magnets inside the compass
  - Upturned cup design mounted on a pin
  - Filled with kerosene or similar liquid to minimize friction and oscillation
- **Explanation**
  The compass card is suspended to allow free movement and is balanced to remain horizontal. The liquid filling reduces friction and dampens oscillations, ensuring accurate readings during aircraft movement.
- **Considerations**
- Ensure the compass is filled with the correct liquid (usually kerosene) to minimize friction.
- Check for proper alignment and serviceability before flight.
- **Special Circumstances**
- If the compass is suspected to be inaccurate after a hard landing or severe turbulence, it must be checked and possibly swung by mechanics.

Compass Deviation and Variation

> Compass variation is the angular difference between true north (geographic north) and magnetic north, which changes location over time. Deviation is the error caused by local magnetic fields within the aircraft, such as those from electronic devices or metal components.

- **Keypoints**
  - Variation is the difference between true north and magnetic north, measured in degrees.
  - Isogonals are lines connecting points of equal variation; agonic lines connect points where variation is zero.
  - Deviation is caused by local magnetic fields from onboard equipment.

    - Compass deviation card is used to correct for deviation.
- **Explanation**
  Pilots use charts to determine local variation and refer to the compass deviation card for corrections. For example, to fly a heading of 360, if the deviation card indicates a correction, the pilot adjusts the heading accordingly.
- **Examples**
  > If a pilot wants to fly north (360), but the deviation card says to steer 359, the pilot must adjust the heading to 359 to compensate for deviation.

    - Check the desired heading (e.g., 360 for north).
    - Refer to the deviation card for the correction (e.g., steer 359).
    - Adjust the aircraft heading accordingly.
- **Considerations**
- Always check and use the compass deviation card.
- Be aware of onboard devices that may cause deviation.
- **Special Circumstances**
- If new electronic equipment is installed or after a shock, the compass must be swung and the deviation card updated.

Compass Swing and Maintenance

> A compass swing is performed when the accuracy of the compass is in doubt, after modifications involving metal components, after replacing radio or electrical equipment, or after the compass has been subjected to shock (e.g., hard landing or turbulence).

- **Keypoints**
    - Performed when compass accuracy is suspect.
    - Required after modifications or equipment changes.
    - Necessary after shocks or hard landings.
- **Explanation**
  Mechanics remove and open the compass to adjust it, as the liquid inside and the magnetic components may need recalibration.
- **Considerations**
- Do not attempt to adjust the compass yourself; only qualified mechanics should perform a swing.
- **Special Circumstances**
- If the compass is damaged or inaccurate after a hard landing, report it for maintenance before further flight.

Magnetic Dip and Its Effects

> Magnetic dip is the inclination of the Earth's magnetic field lines relative to the horizontal. At the equator, dip is zero; at the poles, it is maximum (vertical). The magnetic compass tilts according to these lines, causing errors near the poles.

- **Keypoints**
  - Dip is zero at the magnetic equator (clinic line).
  - Dip is maximum (vertically downwards) at the north pole and upwards at the south pole.
  - In Europe, compass dip is between 55 to 60 degrees to horizontal.
- **Explanation**
  As the aircraft moves closer to the poles, the compass tilts, causing reading errors. This is less significant near the equator.
- **Considerations**
- Be aware of increased compass errors when flying near the poles.
- **Special Circumstances**
- If flying long distances near the poles, expect significant compass dip and plan accordingly.

Compass Errors During Acceleration and Deceleration

> In the northern hemisphere, accelerating on east or west headings causes the compass to indicate a turn toward north; decelerating causes a turn toward south. The mnemonic is ANS: Accelerate North, Decelerate South. In the southern hemisphere, the effect is reversed.

- **Keypoints**
  - Acceleration on east/west headings in the northern hemisphere causes apparent turn to north.
  - Deceleration causes apparent turn to south.
  - No error when accelerating/decelerating northbound or southbound.
  - Mnemonic: ANS (Accelerate North, Decelerate South).
- **Explanation**
  This error is due to the position of the magnetic compass relative to the Earth's field. It is demonstrated in simulators and must be memorized for exams.
- **Examples**
  > When accelerating on runway 04 (heading 044) in Spain (northern hemisphere), the compass tilts and indicates a turn toward north. When decelerating, it indicates a turn toward south.

  - Set heading to 044.
  - Accelerate and observe compass indicating a turn toward north.
  - Decelerate and observe compass indicating a turn toward south.

- **Considerations**
- Remember the ANS mnemonic for exams and practical flying.
- Be aware of hemisphere-specific differences.
- **Special Circumstances**
- If flying in the southern hemisphere, reverse the mnemonic: accelerate south, decelerate north.

Turning Errors: Undershoot North, Overshoot South

> When turning from east or west toward north, the magnetic compass lags behind the direction indicator by approximately 30 degrees. When turning toward south, the compass leads the indicator by about 30 degrees. This error is present in both hemispheres.

- **Keypoints**
  - Turning toward north: compass lags, undershoot the heading.
  - Turning toward south: compass leads, overshoot the heading.
  - Difference between compass and indicator is about 30 degrees.
- **Explanation**
  During a turn, pilots must anticipate the lag or lead and adjust their roll-out point accordingly. For example, when turning from east to north, stop the turn when the compass reads 030 to achieve a heading of 360 on the indicator.
- **Examples**
  > When turning from heading 090 (east) to 360 (north), the direction indicator shows 060 while the compass reads 075. Continue turning until the compass reads 030, then level the wings; the indicator will show 360.

  - Set heading to 090.
  - Begin turn to 360.
  - Observe indicator and compass readings.
  - Stop turn when compass reads 030; indicator will show 360 after stabilization.
- **Considerations**
- Always anticipate and correct for turning errors during heading changes.
- Use the direction indicator for precise turns in flight.
- **Special Circumstances**
- If only the magnetic compass is available (e.g., electrical failure), be especially cautious of turning errors.

Use of Direction Indicator vs. Magnetic Compass

> In practical flight, pilots primarily use the direction indicator for heading changes, as it is less susceptible to errors than the magnetic compass. The magnetic compass

> serves as a backup, especially if the vacuum or electrical systems fail.

- **Keypoints**
  - Direction indicator is primary for heading changes.
  - Magnetic compass is backup in case of system failure.
  - Compass errors must be understood for emergencies.
- **Explanation**
  During normal operations, the direction indicator is more reliable. The magnetic compass is used for cross-checking and as a backup.
- **Considerations**
- Regularly cross-check the direction indicator with the magnetic compass.
- **Special Circumstances**
- If the direction indicator fails, rely on the magnetic compass and account for its errors.

Difference between Magnetic Compass and Direction Indicator

> The magnetic compass and direction indicator are both used for navigation in aircraft, but they behave differently during turns. The magnetic compass can lead or lag behind the direction indicator depending on the direction of the turn, and pilots must understand these differences to navigate accurately.

- **Keypoints**
  - When turning northbound, the direction indicator leads the magnetic compass.
  - When turning southbound, the magnetic compass leads the direction indicator.
  - Pilots must anticipate the lag or lead to level the wings at the correct heading.
  - The error between the two instruments can be approximately 30 degrees during certain maneuvers.
- **Explanation**
  During a right turn, for example, if the pilot wants to fly heading 210, they must level the wings when the magnetic compass reads 210, as the direction indicator will already be at 180. This is due to the lag or lead of the instruments during turns. The pilot must understand when to stop the turn based on the readings of both instruments.
- **Examples**
  > When turning from east to north, the pilot must stop turning at 030 on the direction indicator to be facing 0 (north). The difference between the stopping turn and the desired direction is 30 degrees.

  - The direction indicator and magnetic compass do not always match during turns.

    - The pilot observes the direction indicator and stops the turn at 030 to achieve a north heading.
    - This demonstrates the approximate 30-degree error that can occur.
- **Considerations**
- Always be aware of the lag or lead between the magnetic compass and direction indicator.
- Understand the approximate 30-degree error during turns.
- Level the wings at the correct instrument reading to achieve the desired heading.
- **Special Circumstances**
- If the direction indicator fails, rely on the magnetic compass for heading information.
- If both primary and backup systems fail, use alternate static ports for pressure readings.

Importance of Backup Instruments in Aviation

> Aircraft are equipped with multiple redundant systems and backup instruments to ensure safety in case of instrument failure. The magnetic compass serves as a backup to the direction indicator, and there are also multiple static ports for pressure readings.

- **Keypoints**
    - The magnetic compass is independent of the aircraft's main systems and serves as a backup.
    - Direction indicators and attitude indicators can fail; pilots must be prepared to use backups.
    - Aircraft may have two static ports and an alternate static port for redundancy.
    - Redundancy is critical for safety and is not just additional weight or workload.
- **Explanation**
  If the direction indicator or attitude indicator fails, the pilot can use the magnetic compass to maintain heading. Similarly, if one static port fails, the alternate static port can be used. These redundancies are built into aircraft systems to ensure continued safe operation in the event of failures.
- **Examples**
  > If the direction indicator fails during flight, the pilot must rely on the magnetic compass for heading information, despite its known errors and lag/lead characteristics.

    - The pilot switches to using the magnetic compass.
    - The pilot must account for the compass errors during turns.
    - Understanding the limitations and behavior of the compass is essential for safe navigation.

- **Considerations**
- Always check that backup instruments are functional before flight.
- Understand the limitations and errors associated with backup instruments.
- Do not underestimate the importance of redundancy in flight systems.
- **Special Circumstances**
- If all direction indicators fail, use the magnetic compass as the sole source for heading.
- If both static ports fail, use the alternate static port for pressure readings.

Approximate 30-Degree Error in Compass Readings During Turns

> During certain turns, especially from east to north, there is an approximate 30-degree error between the magnetic compass and the direction indicator. Pilots must be aware of this error to stop the turn at the correct heading.

- **Keypoints**
  - The error is not always exactly 30 degrees but is approximately so in specific maneuvers.
  - The error is most noticeable when turning from east to north or similar headings.
  - Pilots must anticipate and correct for this error during flight.
- **Explanation**
  When turning from east to north, the pilot must stop the turn at 030 on the direction indicator to be facing north (0 degrees). This demonstrates the approximate 30-degree error that can occur between the instruments during turns.
- **Examples**
  > Pilot turns from east to north and must stop at 030 on the direction indicator to be on a north heading, showing the 30-degree error.

  - Pilot observes the direction indicator during the turn.
  - Stops the turn at 030 to achieve a north heading.
  - This compensates for the lag/lead between the instruments.
- **Considerations**
- Be aware that the 30-degree error is approximate and may vary.
- Always verify heading after completing a turn.
- **Special Circumstances**
- If the error is significantly more or less than 30 degrees, check for instrument malfunction.

Electronic Flight Instrument System (EFIS)

> EFIS, commonly called glass cockpit, consists of the Primary Flight Display (PFD) and Multifunction Display (MFD). The PFD shows artificial horizon and azimuth information, while the MFD displays additional information such as engine parameters and navigation. EFIS-equipped aircraft require computers to process raw data from instruments and correct for errors.

- **Keypoints**
  - EFIS includes PFD and MFD.
  - PFD displays artificial horizon, azimuth, altimeter, airspeed, attitude, and direction.
  - MFD provides engine, navigation, and other data.
  - EFIS requires Air Data Computer (ADC) for error correction.
  - Glass cockpit allows flexible display configurations.
- **Explanation**
  EFIS integrates multiple flight instruments into digital displays, improving situational awareness and reducing pilot workload. The system processes raw sensor data and presents it in a user-friendly format.
- **Examples**
  > In modern aircraft, the EFIS replaces traditional analog gauges with digital screens, allowing pilots to view flight, navigation, and engine data on configurable displays.

  - The PFD shows critical flight information such as attitude, altitude, and airspeed.
  - The MFD can be set to display maps, engine status, or other relevant data.
  - Pilots can split screens or customize layouts as needed.
- **Considerations**
- Ensure computers are functioning to process and correct instrument data.
- Understand how to configure and interpret EFIS displays.
- **Special Circumstances**
- If the EFIS display fails, revert to backup analog instruments if available.

Air Data Computer (ADC)

> The Air Data Computer processes raw data from the altimeter, airspeed indicator, and other sensors, correcting for errors and providing accurate information such as wind direction, ground speed, and true airspeed.

- **Keypoints**
  - ADC computes corrections for instrument errors.
  - Displays wind direction, ground speed, and true airspeed.
  - Essential for accurate flight data in EFIS-equipped aircraft.

- **Explanation**
  The ADC takes sensor inputs and applies necessary corrections, ensuring that pilots receive reliable data for navigation and aircraft control.
- **Considerations**
- Monitor ADC performance for accurate flight data.
- **Special Circumstances**
- If ADC malfunctions, cross-check with backup instruments and report discrepancies.

Attitude and Heading Reference System (AHRS)

> AHRS uses gyroscopes and accelerometers to provide attitude (pitch, roll, yaw) and heading information. It replaces traditional mechanical gyros and is essential for modern flight displays.

- **Keypoints**
  - AHRS provides attitude and heading data.
  - Uses gyroscopes that must spin up before operation.
  - Requires aircraft to remain stationary during initialization.
- **Explanation**
  AHRS systems improve reliability and accuracy over mechanical gyros, integrating with EFIS for seamless flight data presentation.
- **Considerations**
- Ensure aircraft is stationary during AHRS initialization.
- **Special Circumstances**
- If AHRS fails to initialize, check for aircraft movement or system faults.

Display Technologies in Aircraft

> Aircraft displays have evolved from cathode ray tube (CRT) technology to liquid crystal display (LCD) and active matrix LCD. CRTs consume more power and generate more heat, requiring extensive ventilation, while LCDs are more efficient.

- **Keypoints**
  - CRT displays are older, power-hungry, and heat-producing.
  - LCD and active matrix LCD are modern, efficient, and cooler.
  - Display technology impacts aircraft power and cooling requirements.
- **Explanation**
  Transitioning to LCD technology reduces aircraft weight, power consumption, and maintenance needs.
- **Considerations**
- Be aware of display type for troubleshooting and maintenance.

Gyroscope Rigidity and Precession

> Gyroscope rigidity depends on rotor spin speed, rotor mass, and mass distribution (rotor radius). When a force is applied to a spinning gyroscope, the resulting movement (precession) occurs 90 degrees further in the direction of rotation.

- **Keypoints**
  - Rigidity increases with higher spin speed, greater mass, and larger radius.
  - Precession is the movement 90 degrees from the applied force.
  - Gyroscopes are used in several flight instruments.
- **Explanation**
  Understanding gyroscope behavior is critical for interpreting instrument readings and diagnosing faults.
- **Examples**
  > A blocked vacuum pump air filter restricts airflow, reducing gyroscope performance and instrument accuracy.

  - Debris in the filter blocks air passage.
  - Reduced airflow means gyros are not driven freely.
  - Instrument accuracy decreases due to lower air pressure.
- **Considerations**
- Keep vacuum pump air filters clear of debris.
- Monitor for signs of instrument inaccuracy.
- **Special Circumstances**
- If filter is clogged with dust, replace it; if blocked by a large object, clean it.

Aircraft Alerting Systems

> Aircraft alerting systems provide warnings, cautions, and advisories to the crew. Warnings require immediate action, cautions require monitoring, and advisories provide awareness. Alerts can be visual (red, yellow, white), oral (bells, buzzers, spoken messages), or tactile (stick shaker).

- **Keypoints**
  - Three alert levels: warning (red), caution (yellow), advisory (white).
  - Visual alerts use color coding for urgency.
  - Oral alerts include bells, buzzers, and spoken messages.
  - Tactile alerts (e.g., stick shaker) are used in larger aircraft.
- **Explanation**
  Alerting systems are designed to draw pilot attention to critical issues and guide appropriate responses.
- **Examples**

> Stall warning systems use red lights and audible buzzers to alert pilots of an impending stall. In some aircraft, a flap or whistler mechanism is used to generate the warning sound.

  - Approaching the critical angle of attack activates the warning.
  - Sound is produced by air movement or mechanical vibration.
  - Pilots must respond promptly to avoid stall.
- **Considerations**
- Understand the meaning of each alert color and sound.
- Monitor caution alerts for potential future action.
- **Special Circumstances**
- If a tactile warning (stick shaker) is activated, immediately take stall recovery actions.

Stall Warning Systems

> Stall warning systems alert pilots when the aircraft approaches the critical angle of attack. They may use a red light, audible buzzer, or mechanical device such as a whistler or flap. The system is activated by negative pressure or movement of the stagnation point.

- **Keypoints**
  - Red light and buzzer indicate stall warning.
  - Mechanical devices (whistler, flap) are used in some aircraft.
  - System is triggered by airflow changes at critical angle of attack.
- **Explanation**
  Pilots must recognize and respond to stall warnings to maintain safe flight.
- **Considerations**
- Test stall warning system during preflight checks.
- **Special Circumstances**
- If stall warning does not activate, do not attempt intentional stalls and report the issue.

Aircraft Communication Frequencies and Wavelengths

> Aircraft communication uses specific frequency bands such as super high frequency (SHF) at 3,500 megahertz. Wavelength can be calculated from frequency (e.g., 150 megahertz corresponds to a wavelength of two meters).

- **Keypoints**
  - SHF band: 3,500 megahertz.
  - 150 megahertz frequency has a wavelength of two meters.

  - Understanding frequencies is essential for radio operation.
- **Explanation**
  Pilots must know the correct frequencies and their properties for effective communication and navigation.
- **Considerations**
- Use correct frequency bands for communication and navigation.

Relationship Between Airspeed, Pitch, and Angle of Attack

> Airspeed, pitch, and angle of attack are interrelated. At normal cruise (e.g., 90 knots), the angle of attack is typically plus one. Increasing speed with the same pitch causes the aircraft to climb, requiring a decrease in angle of attack. Decreasing speed requires increasing pitch to maintain altitude, thus increasing angle of attack.

- **Keypoints**
  - Higher speed with same pitch leads to climb; decrease angle of attack.
  - Lower speed requires increased pitch to maintain altitude; increases angle of attack.
  - Angle of attack changes with airspeed and pitch adjustments.
- **Explanation**
  Pilots adjust pitch and monitor airspeed to control angle of attack and maintain safe flight.
- **Considerations**
- Monitor airspeed and pitch to avoid stalls.
- **Special Circumstances**
- If airspeed decreases to very low, increase pitch to maintain altitude, but beware of approaching stall.

Study and Exam Preparation for HPL (Human Performance and Limitations)

> HPL covers topics related to human physiology and performance in aviation. The course consists of five lessons, with approximately 370 questions in the exam section. Study strategies include reading the material, memorizing questions, and focusing on key concepts.

- **Keypoints**
  - Five lessons in the Bristol course.
  - Exam section contains 370 questions.
  - Study by reading, memorizing, and understanding key points.
- **Explanation**
  Students are advised to study independently, use provided materials, and seek

clarification on important topics such as hypoxia.

- **Considerations**
- Allocate sufficient study time for all three classes.
- Focus on memorizing and understanding exam questions.
- **Special Circumstances**
- If absent for medical reasons, coordinate with instructor for makeup lessons.

Airplane Stall and Visual Angle of Attack

> Discussion about how airplanes are made to stall before reaching the visual angle of attack, specifically on the wings.

- **Keypoints**
  - Airplanes are designed to stall before reaching the visual angle of attack.
  - Stall occurs on the wings.
  - Airflow separation happens before the critical angle.
- **Explanation**
  Speaker 8 asked if the airplane stalls before reaching the visual angle of attack, and Speaker 5 confirmed, explaining that the airflow separates before the critical angle, making it useful for safety.
- **Considerations**
- Ensure understanding of stall mechanics for safety.

Ground Effect: Low Wing vs High Wing

> Comparison of ground effect between low wing and high wing aircraft, focusing on downwash and tendency to float.

- **Keypoints**
  - Low wing aircraft have a tendency to float more due to more squished downwash.
  - High wing aircraft have less tendency to float as the wings are higher over the ground.
  - Downwash is more pronounced on high wing aircraft.
- **Explanation**
  Speaker 5 asked about ground effect, and Speaker 8 explained that low wing aircraft experience more squished downwash, leading to more floating, while high wing aircraft have less tendency to float.
- **Considerations**
- Consider wing position when evaluating ground effect.

Load Factor and Speed Relationship

> Explains how load factor changes with speed, referencing the VG diagram and specific values.

- **Keypoints**
  - When speed decreases, load factor decreases.
  - Load factor is less than 3 in certain cases.
  - At VD, the load factor is 35%.
  - Load factor can decrease to 2.
- **Explanation**
  Speaker 8 and others discussed that as speed decreases, the load factor also decreases, as shown in the VG diagram. Specific values such as VD being 66 or 60 were mentioned, and the load factor can decrease to 2.
- **Considerations**
- Monitor load factor changes during speed adjustments.

VD (Design Dive Speed) and Its Percentage

> VD is a specific speed value, and its percentage is important for flight safety.

- **Keypoints**
  - VD is given as 66 or 60 in the discussion.
  - VD is associated with 35% in the context of load factor.
- **Explanation**
  Speaker 8 mentioned that VD is 66 or 60, and that at VD, the load factor is 35%.
- **Considerations**
- Always verify the correct VD value for the aircraft.

VG Diagram and Gas Load Factor

> The VG diagram is used to show the relationship between speed and gas load factor.

- **Keypoints**
  - As speed decreases, gas load factor increases.
  - Graph shows values such as 300, 200, 400.
- **Explanation**
  Speaker 8 explained that in the VG diagram, as speed decreases, the gas load factor increases, as seen in the graph with values 300, 200, 400.
- **Considerations**
- Interpret VG diagrams accurately for flight performance.

Mnemonic for Converting IIS to TAS

> A mnemonic is used to help remember how to convert IIS (Indicated Airspeed) to TAS (True Airspeed).

- **Keypoints**
  - Mnemonic: 'Ice tea is a very good drink.'
- **Explanation**
  Speaker 2 suggested using the mnemonic 'Ice tea is a very good drink' to remember the conversion process.
- **Considerations**
- Use mnemonics to aid memory in technical conversions.

Stress and Speed Factor in Flight

> Discussion on how stress increases with speed and how reducing speed affects the load factor.

- **Keypoints**
  - Increased speed leads to increased stress.
  - Reducing speed reduces the load factor.
  - Speed factor example: 7.3.
- **Explanation**
  Speaker 8 explained that as speed increases, stress increases. Reducing speed reduces the load factor, and a speed factor of 7.3 was mentioned.
- **Considerations**
- Monitor stress and load factor during speed changes.

Knowledge Retention and Questioning

> Strategies for retaining knowledge and the importance of questioning in learning.

- **Keypoints**
  - Scrap knowledge after reading to reinforce understanding.
  - Answering and asking questions helps retention.
- **Explanation**
  Speaker 8 discussed that after reading, scrapping knowledge (reviewing or testing oneself) helps retention, and that being able to answer or ask questions is important.
- **Considerations**
- Encourage active questioning and review.

Calibrated Truth and Compressibility

> Terms discussed as possible names for a concept, possibly related to airspeed or measurement.

- **Keypoints**
  - Calibrated Truth and Compressibility are terms under consideration.
- **Explanation**
  Speaker 6 and Speaker 3 discussed whether a concept should be called Calibrated Truth or Compressibility.

Q&A Process in Lectures

> The process of asking and answering questions during the lecture, including the use of the Q&A section.

- **Keypoints**
  - Questions can be asked in the Q&A section.
  - Repeating questions and answers helps understanding.
- **Explanation**
  Speaker 5 encouraged participants to ask questions in the Q&A section and repeated questions for clarity.
- **Considerations**
- Utilize Q&A sections for clarification.

Assignments & Suggestions

- For the exam, memorize the mnemonic: Accelerate North, Decelerate South (ANS) for the northern hemisphere, and the reverse for the southern hemisphere.
- Memorize the rule: undershoot North, overshoot South for compass turning errors.
- Study for all three classes during the one-hour period after the lecture on 2025-05-19.
- Read and review pages 13 to 16 from the specified topic, focusing on the two important pages for the upcoming test.
- Prepare for HPL (Human Performance and Limitations) lessons starting on 2025-05-20, including reading and memorizing key questions.
- If you have any questions during study, ask the instructor.