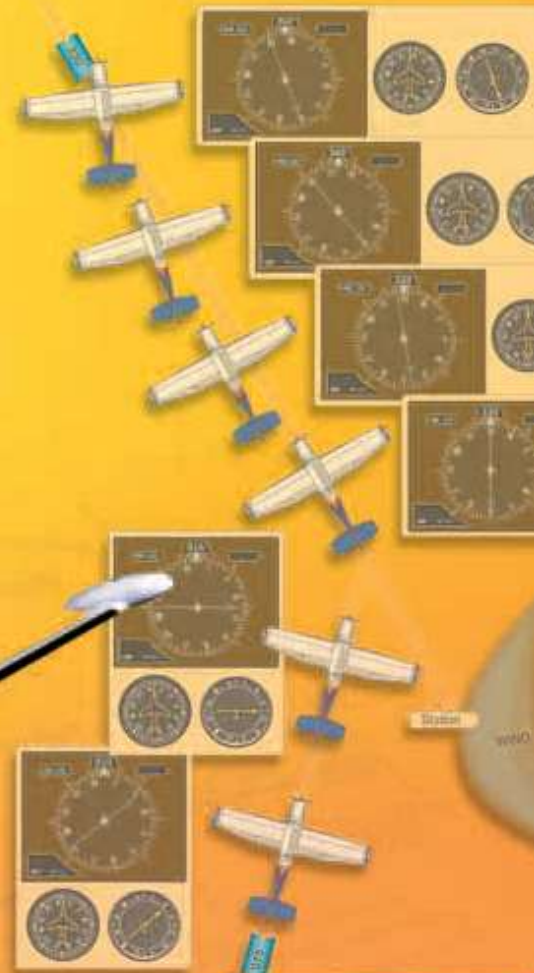


Instrument Flying Handbook



U.S. Department
of Transportation
**FEDERAL AVIATION
ADMINISTRATION**





Chapter 6, Section I

Airplane Attitude Instrument Flying

Using Analog Instrumentation

Introduction

Attitude instrument flying is defined as the control of an aircraft's spatial position by using instruments rather than outside visual references. Today's aircraft come equipped with analog and/or digital instruments. Analog instrument systems are mechanical and operate with numbers representing directly measurable quantities, such as a watch with a sweep second hand. In contrast, digital instrument systems are electronic and operate with numbers expressed in digits. Although more manufacturers are providing aircraft with digital instrumentation, analog instruments remain more prevalent. This section acquaints the pilot with the use of analog flight instruments.

Learning Methods

Attitude Instrument Flying Using the Control and Performance Method

Aircraft performance is achieved by controlling the aircraft attitude and power. Aircraft attitude is the relationship of both the aircraft's pitch and roll axes in relation to the Earth's horizon. An aircraft is flown in instrument flight by controlling the attitude and power, as necessary, to produce both controlled and stabilized flight without reference to a visible horizon. This overall process is known as the control and performance method of attitude instrument flying. Starting with basic instrument maneuvers, this process can be applied through the use of control, performance, and navigation instruments resulting in a smooth flight from takeoff to landing.

The control instruments display immediate attitude and power indications and are calibrated to permit those respective adjustments in precise increments. In this discussion, the term “power” is used in place of the more technically correct term “thrust or drag relationship.” Control is determined by reference to the attitude and power indicators. Power indicators vary with aircraft and may include manifold pressure, tachometers, fuel flow, etc. *[Figure 6-1]*

The performance instruments indicate the aircraft's actual performance. Performance is determined by reference to the altimeter, airspeed, or vertical speed indicator (VSI).
[Figure 6-2]

The navigation instruments indicate the position of the aircraft in relation to a selected navigation facility or fix. This group of instruments includes various types of course indicators, range indicators, glideslope indicators, and bearing pointers. [Figure 6-3] Newer aircraft with more technologically advanced instrumentation provide blended information, giving the pilot more accurate positional information.

1. Establish an attitude and power setting on the control instruments that results in the desired performance. Known or computed attitude changes and approximated power settings helps to reduce the pilot's workload.
2. Trim (fine tune the control forces) until control pressures are neutralized. Trimming for hands-off flight is essential for smooth, precise aircraft control.



Figure 6-1. Control instruments.



Figure 6-2. Performance instruments.



Figure 6-3. Navigation instruments.

3. Cross-check the performance instruments to determine if the established attitude or power setting is providing the desired performance. The cross-check involves both seeing and interpreting. If a deviation is noted, determine the magnitude and direction of adjustment required to achieve the desired performance.
4. Adjust the attitude and/or power setting on the control instruments as necessary.

Aircraft Control During Instrument Flight

Attitude Control

Proper control of aircraft attitude is the result of proper use of the attitude indicator, knowledge of when to change the

attitude, and then smoothly changing the attitude a precise amount. The attitude reference provides an immediate, direct, and corresponding indication of any change in aircraft pitch or bank attitude.

Pitch Control

Changing the “pitch attitude” of the miniature aircraft or fuselage dot by precise amounts in relation to the horizon makes pitch changes. These changes are measured in degrees, or fractions thereof, or bar widths depending upon the type of attitude reference. The amount of deviation from the desired performance determines the magnitude of the correction.

Bank Control

Bank changes are made by changing the “bank attitude” or bank pointers by precise amounts in relation to the bank scale. The bank scale is normally graduated at 0°, 10°, 20°, 30°, 60°, and 90° and is located at the top or bottom of the attitude reference. Bank angle use normally approximates the degrees to turn, not to exceed 30°.

Power Control

Proper power control results from the ability to smoothly establish or maintain desired airspeeds in coordination with attitude changes. Power changes are made by throttle adjustments and reference to the power indicators. Power indicators are not affected by such factors as turbulence, improper trim, or inadvertent control pressures. Therefore, in most aircraft little attention is required to ensure the power setting remains constant.

Experience in an aircraft teaches a pilot approximately how far to move the throttle to change the power a given amount. Power changes are made primarily by throttle movement, followed by an indicator cross-check to establish a more precise setting. The key is to avoid fixating on the indicators

while setting the power. Knowledge of approximate power settings for various flight configurations helps the pilot avoid overcontrolling power.

Attitude Instrument Flying Using the Primary and Supporting Method

Another basic method for teaching attitude instrument flying classifies the instruments as they relate to control function, as well as aircraft performance. All maneuvers involve some degree of motion about the lateral (pitch), longitudinal (bank/roll), and vertical (yaw) axes. Attitude control is stressed in this handbook in terms of pitch control, bank control, power control, and trim control. Instruments are grouped as they relate to control function and aircraft performance as pitch control, bank control, power control, and trim.

Pitch Control

Pitch control is controlling the rotation of the aircraft about the lateral axis by movement of the elevators. After interpreting the pitch attitude from the proper flight instruments, exert control pressures to effect the desired pitch attitude with reference to the horizon. These instruments include the attitude indicator, altimeter, VSI, and airspeed indicator. [Figure 6-4] The attitude indicator displays a direct indication of the aircraft’s pitch attitude while the other pitch attitude control instruments indirectly indicate the pitch attitude of the aircraft.

Attitude Indicator

The pitch attitude control of an aircraft controls the angular relationship between the longitudinal axis of the aircraft and the actual horizon. The attitude indicator gives a direct and immediate indication of the pitch attitude of the aircraft. The aircraft controls are used to position the miniature aircraft in relation to the horizon bar or horizon line for any pitch attitude required. [Figure 6-5]



Figure 6-4. Pitch instruments.



Figure 6-5. Attitude indicator.

The miniature aircraft should be placed in the proper position in relation to the horizon bar or horizon line before takeoff. The aircraft operator's manual explains this position. As soon as practicable in level flight and at desired cruise airspeed, the miniature aircraft should be moved to a position that aligns its wings in front of the horizon bar or horizon line. This adjustment can be made any time varying loads or other conditions indicate a need. Otherwise, the position of the miniature aircraft should not be changed for flight at other than cruise speed. This is to make sure that the attitude indicator displays a true picture of pitch attitude in all maneuvers.

When using the attitude indicator in applying pitch attitude corrections, control pressure should be extremely light. Movement of the horizon bar above or below the miniature aircraft of the attitude indicator in an airplane should not exceed one-half the bar width. [Figure 6-6] If further change is required, an additional correction of not more than one-half horizon bar wide normally counteracts any deviation from normal flight.



Figure 6-6. Pitch correction using the attitude indicator.

Altimeter

If the aircraft is maintaining level flight, the altimeter needles maintain a constant indication of altitude. If the altimeter indicates a loss of altitude, the pitch attitude must be adjusted upward to stop the descent. If the altimeter indicates a gain in altitude, the pitch attitude must be adjusted downward to stop the climb. [Figure 6-7] The altimeter can also indicate the pitch attitude in a climb or descent by how rapidly the needles move. A minor adjustment in pitch attitude may be made to control the rate at which altitude is gained or lost. Pitch attitude is used only to correct small altitude changes caused by external forces, such as turbulence or up and down drafts.



Figure 6-7. Pitch correction using the altimeter.

Vertical Speed Indicator (VSI)

In flight at a constant altitude, the VSI (sometimes referred to as vertical velocity indicator or rate-of-climb indicator) remains at zero. If the needle moves above zero, the pitch attitude must be adjusted downward to stop the climb and return to level flight. Prompt adjustments to the changes in the indications of the VSI can prevent any significant change in altitude. [Figure 6-8] Turbulent air causes the needle to fluctuate near zero. In such conditions, the average of the



Figure 6-8. Vertical speed indicator.

fluctuations should be considered as the correct reading. Reference to the altimeter helps in turbulent air because it is not as sensitive as the VSI.

Vertical speed is represented in feet per minute (fpm). [Figure 6-8] The face of the instrument is graduated with numbers such as 1, 2, 3, etc. These represent thousands of feet up or down in a minute. For instance, if the pointer is aligned with .5 ($\frac{1}{2}$ of a thousand or 500 fpm), the aircraft climbs 500 feet in one minute. The instrument is divided into two regions: one for climbing (up) and one for descending (down).

During turbulence, it is not uncommon to see large fluctuations on the VSI. It is important to remember that small corrections should be employed to avoid further exacerbating a potentially divergent situation.

Overcorrecting causes the aircraft to overshoot the desired altitude; however, corrections should not be so small that the return to altitude is unnecessarily prolonged. As a guide, the pitch attitude should produce a rate of change on the VSI about twice the size of the altitude deviation. For example, if the aircraft is 100 feet off the desired altitude, a 200 fpm rate of correction would be used.

During climbs or descents, the VSI is used to change the altitude at a desired rate. Pitch attitude and power adjustments are made to maintain the desired rate of climb or descent on the VSI.

When pressure is applied to the controls and the VSI shows an excess of 200 fpm from that desired, overcontrolling is indicated. For example, if attempting to regain lost altitude at the rate of 500 fpm, a reading of more than 700 fpm would indicate overcontrolling. Initial movement of the needle

indicates the trend of vertical movement. The time for the VSI to reach its maximum point of deflection after a correction is called lag. The lag is proportional to speed and magnitude of pitch change. In an airplane, overcontrolling may be reduced by relaxing pressure on the controls, allowing the pitch attitude to neutralize. In some helicopters with servo-assisted controls, no control pressures are apparent. In this case, overcontrolling can be reduced by reference to the attitude indicator.

Some aircraft are equipped with an instantaneous vertical speed indicator (IVSI). The letters "IVSI" appear on the face of the indicator. This instrument assists in interpretation by instantaneously indicating the rate of climb or descent at a given moment with little or no lag as displayed in a VSI.

Occasionally, the VSI is slightly out of calibration and indicates a gradual climb or descent when the aircraft is in level flight. If readjustments cannot be accomplished, the error in the indicator should be considered when the instrument is used for pitch control. For example, an improperly set VSI may indicate a descent of 100 fpm when the aircraft is in level flight. Any deviation from this reading would indicate a change in pitch attitude.

Airspeed Indicator

The airspeed indicator gives an indirect reading of the pitch attitude. With a constant power setting and a constant altitude, the aircraft is in level flight and airspeed remains constant. If the airspeed increases, the pitch attitude has lowered and should be raised. [Figure 6-9] If the airspeed decreases, the pitch attitude has moved higher and should be lowered. [Figure 6-10] A rapid change in airspeed indicates a large change in pitch; a slow change in airspeed indicates a small change in pitch. Although the airspeed indicator is used as a pitch instrument, it may be used in level flight for power control. Changes in pitch are reflected immediately by a change in airspeed. There is very little lag in the airspeed indicator.

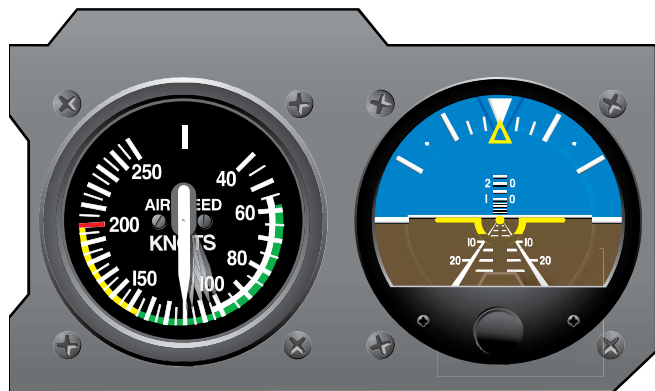


Figure 6-9. Pitch attitude has lowered.

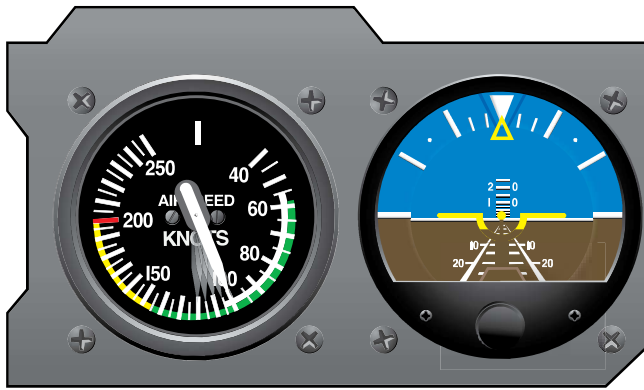


Figure 6-10. Pitch attitude has moved higher.

Pitch Attitude Instrument Cross-Check

The altimeter is an important instrument for indicating pitch attitude in level flight except when used in conditions of exceptionally strong vertical currents, such as thunderstorms. With proper power settings, any of the pitch attitude instruments can be used to hold reasonably level flight attitude. However, only the altimeter gives the exact altitude information. Regardless of which pitch attitude control instrument indicates a need for a pitch attitude adjustment, the attitude indicator, if available, should be used to make the adjustment. Common errors in pitch attitude control are:

- Overcontrolling;
- Improperly using power; and
- Failing to adequately cross-check the pitch attitude instruments and take corrective action when pitch attitude change is needed.

Bank Control

Bank control is controlling the angle made by the wing and the horizon. After interpreting the bank attitude from the

appropriate instruments, exert the necessary pressures to move the ailerons and roll the aircraft about the longitudinal axis. As illustrated in *Figure 6-11*, these instruments include:

- Attitude indicator
- Heading indicator
- Magnetic compass
- Turn coordinator/turn-and-slip indicator

Attitude Indicator

As previously discussed, the attitude indicator is the only instrument that portrays both instantly and directly the actual flight attitude and is the basic attitude reference.

Heading Indicator

The heading indicator supplies the pertinent bank and heading information and is considered a primary instrument for bank.

Magnetic Compass

The magnetic compass provides heading information and is considered a bank instrument when used with the heading indicator. Care should be exercised when using the magnetic compass as it is affected by acceleration, deceleration in flight caused by turbulence, climbing, descending, power changes, and airspeed adjustments. Additionally, the magnetic compass indication will lead and lag in its reading depending upon the direction of turn. As a result, acceptance of its indication should be considered with other instruments that indicate turn information. These include the already mentioned attitude and heading indicators, as well as the turn-and-slip indicator and turn coordinator.



Figure 6-11. Bank instruments.

Turn Coordinator/Turn-and-Slip Indicator

Both of these instruments provide turn information. [Figure 6-12] The turn coordinator provides both bank rate and then turn rate once stabilized. The turn-and-slip indicator provides only turn rate.



Figure 6-12. Turn coordinator and turn-and-slip indicator.

Power Control

A power change to adjust airspeed may cause movement around some or all of the aircraft axes. The amount and direction of movement depends on how much or how rapidly the power is changed, whether single-engine or multiengine airplane or helicopter. The effect on pitch attitude and airspeed caused by power changes during level flight is illustrated in Figures 6-13 and 6-14. During or immediately after adjusting the power control(s), the power instruments should be cross-checked to see if the power adjustment is as desired. Whether or not the need for a power adjustment is indicated by another instrument(s), adjustment is made by cross-checking the power instruments. Aircraft are powered by a variety of powerplants, each powerplant having certain instruments that indicate the amount of power being applied to operate the aircraft. During instrument flight, these instruments must be used to make the required power adjustments.

As illustrated in Figure 6-15, power indicator instruments include:

- Airspeed indicator
- Engine instruments

Airspeed Indicator

The airspeed indicator provides an indication of power best observed initially in level flight where the aircraft is in balance and trim. If in level flight the airspeed is increasing, it can generally be assumed that the power has increased, necessitating the need to adjust power or re-trim the aircraft.

Engine Instruments

Engine instruments, such as the manifold pressure (MP) indicator, provide an indication of aircraft performance for a given setting under stable conditions. If the power conditions are changed, as reflected in the respective engine instrument readings, there is an affect upon the aircraft performance, either an increase or decrease of airspeed. When the propeller rotational speed (revolutions per minute (RPM) as viewed on a tachometer) is increased or decreased on fixed-pitch propellers, the performance of the aircraft reflects a gain or loss of airspeed as well.

Trim Control

Proper trim technique is essential for smooth and accurate instrument flying and utilizes instrumentation illustrated in Figure 6-16. The aircraft should be properly trimmed while executing a maneuver. The degree of flying skill, which ultimately develops, depends largely upon how well the aviator learns to keep the aircraft trimmed.

Airplane Trim

An airplane is correctly trimmed when it is maintaining a desired attitude with all control pressures neutralized. By relieving all control pressures, it is much easier to maintain the



Figure 6-13. An increase in power—increasing airspeed accordingly in level flight.



Figure 6-14. Pitch control and power adjustment required to bring aircraft to level flight.



Figure 6-15. Power instruments.



Figure 6-16. Trim instruments.

aircraft at a certain attitude. This allows more time to devote to the navigation instruments and additional flight deck duties.

An aircraft is placed in trim by:

- Applying control pressure(s) to establish a desired attitude. Then, the trim is adjusted so that the aircraft maintains that attitude when flight controls are released. The aircraft is trimmed for coordinated flight by centering the ball of the turn-and-slip indicator.
- Moving the rudder trim in the direction where the ball is displaced from center. Aileron trim may then be adjusted to maintain a wings-level attitude.
- Using balanced power or thrust when possible to aid in maintaining coordinated flight. Changes in attitude, power, or configuration may require trim adjustments. Use of trim alone to establish a change in aircraft attitude usually results in erratic aircraft control. Smooth and precise attitude changes are best attained by a combination of control pressures and subsequent trim adjustments. The trim controls are aids to smooth aircraft control.

Helicopter Trim

A helicopter is placed in trim by continually cross-checking the instruments and performing the following:

- Using the cyclic-centering button. If the helicopter is so equipped, this relieves all possible cyclic pressures.
- Using the pedal adjustment to center the ball of the turn indicator. Pedal trim is required during all power changes and is used to relieve all control pressures held after a desired attitude has been attained.

An improperly trimmed helicopter requires constant control pressures, produces tension, distracts attention from cross-checking, and contributes to abrupt and erratic attitude control. The pressures felt on the controls should be only those applied while controlling the helicopter.

Adjust the pitch attitude, as airspeed changes, to maintain desired attitude for the maneuver being executed. The bank must be adjusted to maintain a desired rate of turn, and the pedals must be used to maintain coordinated flight. Trim must be adjusted as control pressures indicate a change is needed.

Example of Primary and Support Instruments

Straight-and-level flight at a constant airspeed means that an exact altitude is to be maintained with zero bank (constant heading). The primary pitch, bank, and power instruments used to maintain this flight condition are:

- Altimeter—supplies the most pertinent altitude information and is primary for pitch.

- Heading Indicator—supplies the most pertinent bank or heading information and is primary for bank.
- Airspeed Indicator—supplies the most pertinent information concerning performance in level flight in terms of power output and is primary for power.

Although the attitude indicator is the basic attitude reference, the concept of primary and supporting instruments does not devalue any particular flight instrument, when available, in establishing and maintaining pitch-and-bank attitudes. It is the only instrument that instantly and directly portrays the actual flight attitude. It should always be used, when available, in establishing and maintaining pitch-and-bank attitudes. The specific use of primary and supporting instruments during basic instrument maneuvers is presented in more detail in Chapter 7, Airplane Basic Flight Maneuvers.

Fundamental Skills

During attitude instrument training, two fundamental flight skills must be developed. They are instrument cross-check and instrument interpretation, both resulting in positive aircraft control. Although these skills are learned separately and in deliberate sequence, a measure of proficiency in precision flying is the ability to integrate these skills into unified, smooth, positive control responses to maintain any prescribed flightpath.

Instrument Cross-Check

The first fundamental skill is cross-checking (also called “scanning” or “instrument coverage”). Cross-checking is the continuous and logical observation of instruments for attitude and performance information. In attitude instrument flying, the pilot maintains an attitude by reference to instruments, producing the desired result in performance. Observing and interpreting two or more instruments to determine attitude and performance of an aircraft is called cross-checking. Although no specific method of cross-checking is recommended, those instruments that give the best information for controlling the aircraft in any given maneuver should be used. The important instruments are the ones that give the most pertinent information for any particular phase of the maneuver. These are usually the instruments that should be held at a constant indication. The remaining instruments should help maintain the important instruments at the desired indications, which is also true in using the emergency panel.

Cross-checking is mandatory in instrument flying. In visual flight, a level attitude can be maintained by outside references. However, even then the altimeter must be checked to determine if altitude is being maintained. Due to human error, instrument error, and airplane performance differences in various atmospheric and loading conditions, it is impossible to establish an attitude and have performance remain constant

for a long period of time. These variables make it necessary for the pilot to constantly check the instruments and make appropriate changes in airplane attitude using cross-checking of instruments. Examples of cross-checking are explained in the following paragraphs.

Selected Radial Cross-Check

When the selected radial cross-check is used, a pilot spends 80 to 90 percent of flight time looking at the attitude indicator, taking only quick glances at the other flight instruments (for this discussion, the five instruments surrounding the attitude indicator are called the flight instruments). With this method, the pilot's eyes never travel directly between the flight instruments but move by way of the attitude indicator. The maneuver being performed determines which instruments to look at in the pattern. [Figure 6-17]

Inverted-V Cross-Check

In the inverted-V cross-check, the pilot scans from the attitude indicator down to the turn coordinator, up to the attitude indicator, down to the VSI, and back up to the attitude indicator. [Figure 6-18]

Rectangular Cross-Check

In the rectangular cross-check, the pilot scans across the top three instruments (airspeed indicator, attitude

indicator, and altimeter), and then drops down to scan the bottom three instruments (VSI, heading indicator, and turn instrument). This scan follows a rectangular path (clockwise or counterclockwise rotation is a personal choice). [Figure 6-19]

This cross-checking method gives equal weight to the information from each instrument, regardless of its importance to the maneuver being performed. However, this method lengthens the time it takes to return to an instrument critical to the successful completion of the maneuver.

Common Cross-Check Errors

A beginner might cross-check rapidly, looking at the instruments without knowing exactly what to look for. With increasing experience in basic instrument maneuvers and familiarity with the instrument indications associated with them, a pilot learns what to look for, when to look for it, and what response to make. As proficiency increases, a pilot cross-checks primarily from habit, suiting scanning rate and sequence to the demands of the flight situation. Failure to maintain basic instrument proficiency through practice can result in many of the following common scanning errors, both during training and at any subsequent time.

Fixation, or staring at a single instrument, usually occurs for a reason, but has poor results. For example, a pilot may stare



Figure 6-17. Radial cross-check.



Figure 6-18. Inverted-V cross-check.



Figure 6-19. Rectangular cross-check.

at the altimeter reading 200 feet below the assigned altitude, and wonder how the needle got there. While fixated on the instrument, increasing tension may be unconsciously exerted on the controls, which leads to an unnoticed heading change that leads to more errors. Another common fixation is likely when initiating an attitude change. For example, a shallow bank is established for a 90° turn and, instead of maintaining a cross-check of other pertinent instruments, the pilot stares at the heading indicator throughout the turn. Since the aircraft is turning, there is no need to recheck the heading indicator for approximately 25 seconds after turn entry. The problem here may not be entirely due to cross-check error. It may be related to difficulties with instrument interpretation. Uncertainty about reading the heading indicator (interpretation) or uncertainty because of inconsistency in rolling out of turns (control) may cause the fixation.

Omission of an instrument from a cross-check is another likely fault. It may be caused by failure to anticipate significant instrument indications following attitude changes. For example, in a roll-out from a 180° steep turn, straight-and-level flight is established with reference only to the attitude indicator, and the pilot neglects to check the heading indicator for constant heading information. Because of precession error, the attitude indicator temporarily shows a slight error, correctable by quick reference to the other flight instruments.

Emphasis on a single instrument, instead of on the combination of instruments necessary for attitude information, is an understandable fault during the initial stages of training. It

is a natural tendency to rely on the instrument that is most readily understood, even when it provides erroneous or inadequate information. Reliance on a single instrument is poor technique. For example, a pilot can maintain reasonably close altitude control with the attitude indicator, but cannot hold altitude with precision without including the altimeter in the cross-check.

Instrument Interpretation

The second fundamental skill, instrument interpretation, requires more thorough study and analysis. It begins by understanding each instrument's construction and operating principles. Then, this knowledge must be applied to the performance of the aircraft being flown, the particular maneuvers to be executed, the cross-check and control techniques applicable to that aircraft, and the flight conditions.

For example, a pilot uses full power in a small airplane for a 5-minute climb from near sea level, and the attitude indicator shows the miniature aircraft two bar widths (twice the thickness of the miniature aircraft wings) above the artificial horizon. [Figure 6-20] The airplane is climbing at 500 fpm as shown on the VSI, and at airspeed of 90 knots, as shown on the airspeed indicator. With the power available in this particular airplane and the attitude selected by the pilot, the performance is shown on the instruments. Now, set up the identical picture on the attitude indicator in a jet airplane. With the same airplane attitude as shown in the first example, the VSI in the jet reads 2,000 fpm and the airspeed indicator reads 250 knots.

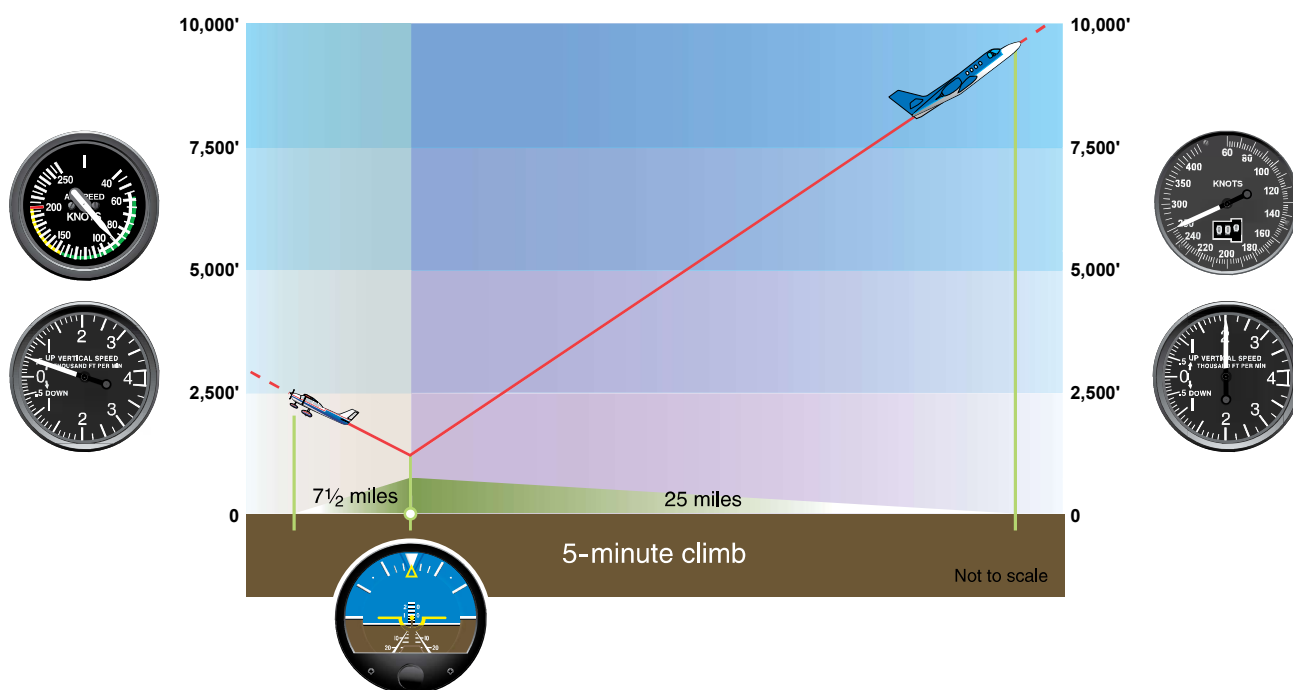


Figure 6-20. Power and attitude equal performance.

As the performance capabilities of the aircraft are learned, a pilot interprets the instrument indications appropriately in terms of the attitude of the aircraft. If the pitch attitude is to be determined, the airspeed indicator, altimeter, VSI, and attitude indicator provide the necessary information. If the bank attitude is to be determined, the heading indicator, turn coordinator, and attitude indicator must be interpreted. For each maneuver, learn what performance to expect and the combination of instruments to be interpreted in order to control aircraft attitude during the maneuver. It is the two fundamental flight skills, instrument cross-check and instrument interpretation, that provide the smooth and seamless control necessary for basic instrument flight as discussed at the beginning of the chapter.