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Instrument Flying Handbook

Instrument Flying Handbook

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FEDERAL AVIATION ADMINISTRATION
Flight Standards Service

Preface

This Instrument Flying Handbook is designed for use by instrument flight instructors and pilots preparing for instrument rating tests. Instructors may find this handbook a valuable training aid as it includes basic reference material for knowledge testing and instrument flight training. Other Federal Aviation Administration (FAA) publications should be consulted for more detailed information on related topics.

This handbook conforms to pilot training and certification concepts established by the FAA. There are different ways of teaching, as well as performing, flight procedures and maneuvers and many variations in the explanations of aerodynamic theories and principles. This handbook adopts selected methods and concepts for instrument flying. The discussion and explanations reflect the most commonly used practices and principles. Occasionally the word “must” or similar language is used where the desired action is deemed critical. The use of such language is not intended to add to, interpret, or relieve a duty imposed by Title 14 of the Code of Federal Regulations (14 CFR).

All of the aeronautical knowledge and skills required to operate in instrument meteorological conditions (IMC) are detailed. Chapters are dedicated to human and aerodynamic factors affecting instrument flight, the flight instruments, attitude instrument flying for airplanes, basic flight maneuvers used in IMC, attitude instrument flying for helicopters, navigation systems, the National Airspace System (NAS), the air traffic control (ATC) system, instrument flight rules (IFR) flight procedures, and IFR emergencies. Clearance shorthand and an integrated instrument lesson guide are also included.

This handbook supersedes Advisory Circular (AC) 61-27C, Instrument Flying Handbook, which was revised in 1980. Comments regarding this handbook should be sent to U.S. Department of Transportation, Federal Aviation Administration, Airman Testing Standards Branch, AFS-630, P.O. Box 25082, Oklahoma City, OK 73125.

The current Flight Standards Service airman training and testing material and subject matter knowledge codes for all airman certificates and ratings can be obtained from the Flight Standards Service web site at: http://afs600.faa.gov.

This publication may be purchased from the Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250-7954, or from the U.S. Government Printing Office (GPO) bookstores located in major cities throughout the United States.

AC 00-2, Advisory Circular Checklist, transmits the current status of FAA ACs and other flight information publications. This checklist is free of charge and may be obtained by sending a request to U.S. Department of Transportation, Subsequent Distribution Office, SVC-121.23, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785. The checklist is also available on the internet at: http://www. faa.gov/abc/ac-chklst/actoc.htm.

Acknowledgments
This book was produced as a combined FAA and industry effort.

Introduction

Is an Instrument Rating Necessary?

The answer to this question depends entirely upon individual needs. Pilots who fly in familiar uncongested areas, stay continually alert to weather developments, and accept an alternative to their original plan, may not need an Instrument Rating. However, some cross-country destinations may take a pilot to unfamiliar airports and/or through high activity areas in marginal visual or instrument meteorological conditions (IMC). Under these conditions, an Instrument Rating may be an alternative to rerouting, rescheduling, or canceling a flight. Many accidents are the result of pilots who lack the necessary skills or equipment to fly in marginal visual meteorological conditions (VMC) or IMC conditions and attempt flight without outside references.

Pilots originally flew aircraft strictly by sight, sound, and feel while comparing the aircraft's attitude to the natural horizon. As aircraft performance increased, pilots required more in-flight information to enhance the safe operation of their aircraft. This information has ranged from a string tied to a wing strut, to development of sophisticated electronic flight information systems (EFIS) and flight management systems (FMS). Interpretation of the instruments and aircraft control have advanced from the "one, two, three" or "needle, ball and airspeed" system to the use of "attitude instrument flying" techniques.

Navigation began by using ground references with dead reckoning and has led to the development of electronic navigation systems. These include the automatic direction finder (ADF), very-high frequency omnidirectional range (VOR), distance measuring equipment (DME), tactical air navigation (TACAN), long range navigation (LORAN), global positioning system (GPS), instrument landing system (ILS), microwave landing system (MLS), and inertial navigation system (INS).

Perhaps you want an Instrument Rating for the same basic reason you learned to fly in the first place—because you like flying. Maintaining and extending your proficiency, once you have the rating, means less reliance on chance and more on skill and knowledge. Earn the rating—not because you might need it sometime, but because it represents achievement and provides training you will use continually and build upon as long as you fly. But most importantly—it means greater safety in flying.

Instrument Rating Requirements

A Private or Commercial pilot who operates an aircraft using an instrument flight rules (IFR) flight plan operates in conditions less than the minimums prescribed for visual flight rules (VFR), or in any flight in Class A airspace, must have an Instrument Rating and meet the appropriate currency requirements.

You will need to carefully review the aeronautical knowledge and experience requirements for the Instrument Rating as outlined in Title 14 of the Code of Federal Regulations (14 CFR) part 61. After completing the FAA Knowledge Test issued for the Instrument Rating, and all the experience requirements have been satisfied, you are eligible to take the practical test. The regulations specify minimum total and pilot in command time requirements. This minimum applies to all applicants—regardless of ability or previous aviation experience.

Training for the Instrument Rating

A person who wishes to add the Instrument Rating to their pilot certificate must first make commitments of time, money, and quality of training. There are many combinations of training methods available. Self-study alone may be adequate preparation to pass the required FAA Knowledge Test for the Instrument Rating. Occasional periods of ground and flight instruction may provide the skills necessary to pass the required test. Or, individuals may choose a training facility that provides comprehensive aviation education and the training necessary to ensure the pilot will pass all the required tests and operate safely in the National Airspace System (NAS). The aeronautical knowledge may be administered by educational institutions, aviation-oriented schools, correspondence courses, and appropriately-rated instructors. Each person must decide for themselves which training program best meets their needs and at the same time maintain a high quality of training. Interested persons should make inquiries regarding the available training at nearby airports, training facilities, in aviation publications, and through the Federal Aviation Administration (FAA) Flight Standards District Office (FSDO).

Although the regulations specify minimum requirements, the amount of instructional time needed is determined not by the regulation, but by the individual's ability to achieve a satisfactory level of proficiency. A professional pilot with diversified flying experience may easily attain a satisfactory level of proficiency in the minimum time required by regulation. Your own time requirements will depend upon a variety of factors, including previous flying experience, rate of learning, basic ability, frequency of flight training, type of aircraft flown, quality of ground school training, and quality of flight instruction, to name a few. The total instructional time you will need, and in general the scheduling of such time, is up to the individual most qualified to judge your proficiency—the instructor who supervises your progress and endorses your record of flight training.

You can accelerate and enrich much of your training by informal study. An increasing number of visual aids and programmed instrument courses are available. The best course is one that includes a well-integrated flight and ground school curriculum. The sequential nature of flying requires that each element of knowledge and skill be learned and applied in the right manner at the right time.

Part of your instrument training may utilize a flight simulator, flight training device, or a personal computer-based aviation training device (PCATD). This ground-based flight training equipment is a valuable tool for developing your instrument cross-check and learning procedures such as intercepting and tracking, holding patterns, and instrument approaches. Once these concepts are fully understood, you can then continue with in-flight training and refine these techniques for full transference of your new knowledge and skills.

Holding the Instrument Rating does not necessarily make you a competent weather pilot. The rating certifies only that you have complied with the minimum experience requirements, that you can plan and execute a flight under IFR, that you can execute basic instrument maneuvers, and that you have shown acceptable skill and judgment in performing these activities. Your Instrument Rating permits you to fly into instrument weather conditions with no previous instrument weather experience. Your Instrument Rating is issued on the assumption that you have the good judgment to avoid situations beyond your capabilities. The instrument training program you undertake should help you not only to develop essential flying skills but also help you develop the judgment necessary to use the skills within your own limits.

Regardless of the method of training selected, the curriculum in appendix 2 provides guidance as to the minimum training required for the addition of an Instrument Rating to a Private or Commercial pilot certificate.

Maintaining the Instrument Rating

Once you hold the Instrument Rating, you may not act as pilot in command under IFR or in weather conditions less than the minimums prescribed for VFR, unless you meet the recent flight experience requirements outlined in part 61. These procedures must be accomplished within the preceding 6 months and include six instrument approaches, holding procedures, and intercepting and tracking courses through the use of navigation systems. If you do not meet the experience requirements during these 6 months, you have another 6 months to meet these minimums. If the requirements still are not met, you must pass an instrument proficiency check, which is an in-flight evaluation by a qualified instrument flight instructor using tasks outlined in the instrument rating practical test standards (PTSs).

The instrument currency requirements must be accomplished under actual or simulated instrument conditions. You may log instrument flight time during the time for which you control the aircraft solely by reference to the instruments. This can be accomplished by wearing a view-limiting device such as a hood, flying an approved flight-training device, or flying in actual IMC.

It takes only one harrowing experience to clarify the distinction between minimum practical knowledge and a thorough understanding of how to apply the procedures and techniques used in instrument flight. Your instrument training is never complete; it is adequate when you have absorbed every foreseeable detail of knowledge and skill to ensure a solution will be available if and when you need it.

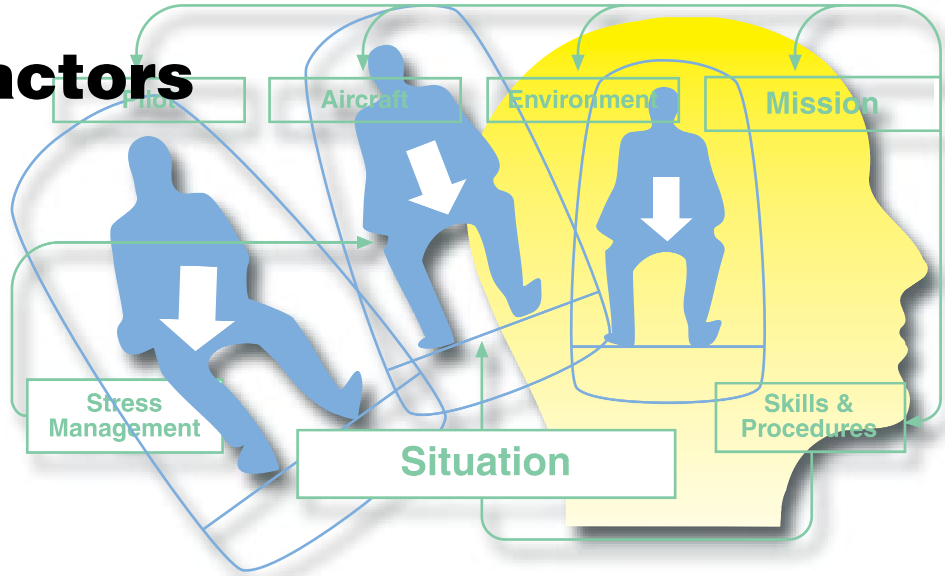
Contents

Chapter 6

Chapter 7

Chapter 1

Human Factors



Introduction

Human factors is a broad field that studies the interaction between people and machines for the purpose of improving performance and reducing errors. As aircraft became more reliable and less prone to mechanical failure, the percentage of accidents related to human factors increased. Some aspect of human factors now accounts for over 80 percent of all accidents. Pilots who have a good understanding of human factors are better equipped to plan and execute a safe and uneventful flight.

Flying in instrument meteorological conditions (IMC) can result in sensations that are misleading to the body's sensory system. A safe pilot needs to understand these sensations and effectively counteract them. Instrument flying requires a pilot to make decisions using all available resources.

The elements of human factors covered in this chapter include sensory systems used for orientation, illusions in flight, physiological and psychological factors, medical factors, aeronautical decision making, and crew/cockpit resource management.

Sensory Systems for Orientation

Orientation is the awareness of the position of the aircraft and of oneself in relation to a specific reference point. Disorientation is the lack of orientation, and **spatial disorientation** specifically refers to the lack of orientation with regard to position in space and to other objects.

Orientation is maintained through the body's sensory organs in three areas: visual, vestibular, and postural. The eyes maintain visual orientation; the motion sensing system in the inner ear maintains vestibular orientation; and the nerves in the skin, joints, and muscles of the body maintain postural orientation. When human beings are in their natural environment, these three systems work well. However, when the human body is subjected to the forces of flight, these senses can provide misleading information. It is this misleading information that causes pilots to become disoriented.

Eyes

During flight in visual meteorological conditions (VMC), the eyes are the major orientation source and usually provide accurate and reliable information. Visual cues usually prevail over false sensations from other sensory systems. When these visual cues are taken away, as they are in IMC, false sensations can cause the pilot to quickly become disoriented.

Human factors: A multidisciplinary field encompassing the behavioral and social sciences, engineering, and physiology, to consider the variables that influence individual and crew performance for the purpose of reducing errors.

Orientation: Awareness of the position of the aircraft and of oneself in relation to a specific reference point.

Spatial disorientation: The state of confusion due to misleading information being sent to the brain from various sensory organs, resulting in a lack of awareness of the aircraft position in relation to a specific reference point.

The only effective way to counter these false sensations is to recognize the problem, disregard the false sensations, and while relying totally on the flight instruments, use the eyes to determine the aircraft attitude. The pilot must have an understanding of the problem and the self-confidence to control the aircraft using only instrument indications.

Ears

The inner ear has two major parts concerned with orientation, the semicircular canals and the otolith organs. [Figure 1-1] The semicircular canals detect angular acceleration of the body while the otolith organs detect linear acceleration and gravity. The semicircular canals consist of three tubes at right angles to each other, each located on one of the three axes: pitch, roll, or yaw. Each canal is filled with a fluid called endolymph fluid. In the center of the canal is the cupola, a gelatinous structure that rests upon sensory hairs located at the end of the **vestibular** nerves.

Our motion sensing system is located in each inner ear in the approximate position shown.

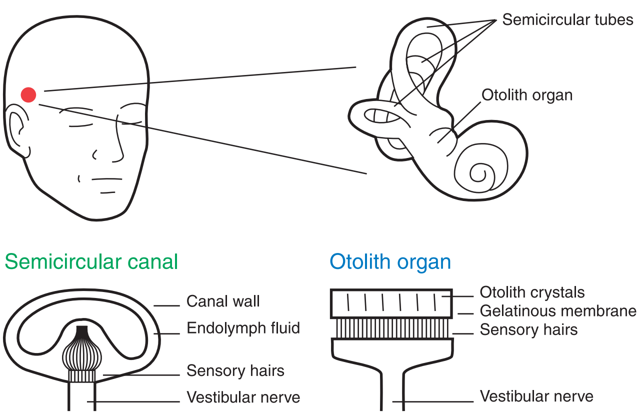


Figure 1-1. *Inner ear orientation.*

Figure 1-2 illustrates what happens during a turn. When the ear canal is moved in its plane, the relative motion of the fluid moves the cupola, which, in turn, stimulates the sensory hairs to provide the sensation of turning. This effect can be demonstrated by taking a glass filled with water and turning it slowly. The wall of the glass is moving, yet the water is not. If these sensory hairs were attached to the glass, they would be moving in relation to the water, which is still standing still.

Vestibular: The central cavity of the bony labyrinth of the ear, or the parts of the membranous labyrinth that it contains.

The semicircular tubes are arranged at approximately right angles to each other, in the roll, pitch, and yaw axes.

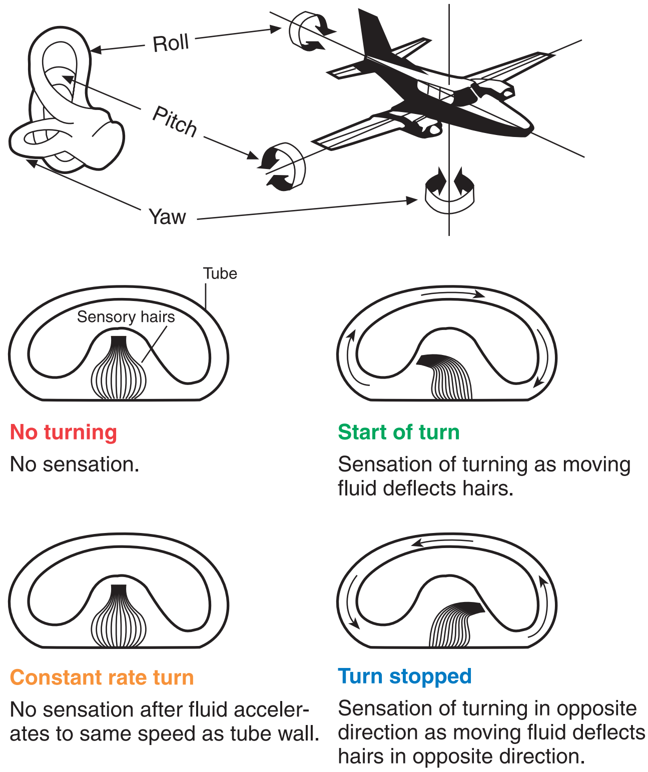


Figure 1-2. *Angular acceleration.*

The ear was designed to detect turns of a rather short duration. After a short period of time (approximately 20 seconds), the fluid accelerates due to friction between the fluid and the canal wall. Eventually, the fluid will move at the same speed as the ear canal. Since both are moving at the same speed, the sensory hairs detect no relative movement and the sensation of turning ceases. This can also be illustrated with the glass of water. Initially, the glass moved and the water did not. Yet, continually turning the glass would result in the water accelerating and matching the speed of the wall of the glass.

The pilot is now in a turn without any sensation of turning. When the pilot stops turning, the ear canal stops moving but the fluid does not. The motion of the fluid moves the cupola and therefore, the sensory hairs in the opposite direction. This creates the sensation of turning in the opposite direction even though the turn has stopped.

The otolith organs detect linear acceleration and gravity in a similar way. Instead of being filled with a fluid, a gelatinous membrane containing chalk-like crystals covers the sensory hairs. When the pilot tilts his/her head, the weight of these crystals causes this membrane to shift due to gravity and the sensory hairs detect this shift. The brain orients this new position to what it perceives as vertical. Acceleration and deceleration also cause the membrane to shift in a similar manner. Forward acceleration gives the illusion of the head tilting backward. [Figure 1-3]

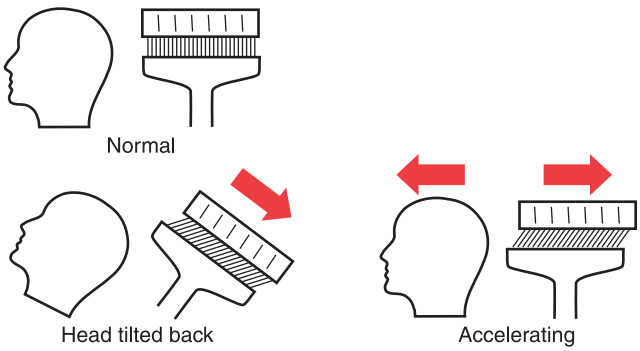


Figure 1-3. *Linear acceleration.*

Nerves

Nerves in the body's skin, muscles, and joints constantly send signals to the brain, which signals the body's relation to gravity. These signals tell the pilot his/her current position. Acceleration will be felt as the pilot is pushed back into the seat. Forces created in turns can lead to false sensations of the true direction of gravity, and may give the pilot a false sense of which way is up.

Uncoordinated turns, especially climbing turns, can cause misleading signals to be sent to the brain. Skids and slips give the sensation of banking or tilting. Turbulence can create motions that confuse the brain as well. Pilots need to be aware that fatigue or illness can exacerbate these sensations and ultimately lead to subtle incapacitation.

Illusions Leading to Spatial Disorientation

The sensory system responsible for most of the illusions leading to spatial disorientation is the vestibular system in the inner ear. The major illusions leading to spatial disorientation are covered below.

Inner Ear

The Leans

A condition called the **leans** can result when a banked attitude, to the left for example, may be entered too slowly to set in motion the fluid in the "roll" semicircular tubes. [Figure 1-2] An abrupt correction of this attitude can now set the fluid in motion, creating the illusion of a banked attitude to the right. The disoriented pilot may make the error of rolling the aircraft into the original left-banked attitude or, if level flight is maintained, will feel compelled to lean to the left until this illusion subsides.

Coriolis Illusion

The pilot has been in a turn long enough for the fluid in the ear canal to move at the same speed as the canal. A movement of the head in a different plane, such as looking at something in a different part of the cockpit, may set the fluid moving thereby creating the strong illusion of turning or accelerating on an entirely different axis. This is called **Coriolis illusion**. This action causes the pilot to think the aircraft is doing a maneuver that it is not. The disoriented pilot may maneuver the aircraft into a dangerous attitude in an attempt to correct the aircraft's perceived attitude.

For this reason, it is important that pilots develop an instrument cross-check or scan that involves minimal head movement. Take care when retrieving charts and other objects in the cockpit—if you drop something, retrieve it with minimal head movement and be alert for the Coriolis illusion.

Graveyard Spiral

As in other illusions, a pilot in a prolonged coordinated, constant-rate turn, will have the illusion of not turning. During the recovery to level flight, the pilot will experience the sensation of turning in the opposite direction. The disoriented pilot may return the aircraft to its original turn. Because an

Leans: An abrupt correction of a banked attitude, entered too slowly to stimulate the motion sensing system in the inner ear, can create the illusion of banking in the opposite direction.

Coriolis illusion: An abrupt head movement, while in a prolonged constant-rate turn that has ceased stimulating the motion sensing system, can create the illusion of rotation or movement in an entirely different axis.

aircraft tends to lose altitude in turns unless the pilot compensates for the loss in lift, the pilot may notice a loss of altitude. The absence of any sensation of turning creates the illusion of being in a level descent. The pilot may pull back on the controls in an attempt to climb or stop the descent. This action tightens the spiral and increases the loss of altitude; hence, this illusion is referred to as a **graveyard spiral**. At some point, this could lead to a loss of control by the pilot.

Somatogravic Illusion

A rapid acceleration, such as experienced during takeoff, stimulates the otolith organs in the same way as tilting the head backwards. This action creates the **somatogravic illusion** of being in a nose-up attitude, especially in situations without good visual references. The disoriented pilot may push the aircraft into a nose-low or dive attitude. A rapid deceleration by quick reduction of the throttle(s) can have the opposite effect, with the disoriented pilot pulling the aircraft into a nose-up or stall attitude.

Inversion Illusion

An abrupt change from climb to straight-and-level flight can stimulate the otolith organs enough to create the illusion of tumbling backwards, or **inversion illusion**. The disoriented pilot may push the aircraft abruptly into a nose-low attitude, possibly intensifying this illusion.

Elevator Illusion

An abrupt upward vertical acceleration, as can occur in an updraft, can stimulate the otolith organs to create the illusion of being in a climb. This is called **elevator illusion**. The disoriented pilot may push the aircraft into a nose-low attitude. An abrupt downward vertical acceleration, usually in a downdraft, has the opposite effect, with the disoriented pilot pulling the aircraft into a nose-up attitude.

Visual

Two illusions that lead to spatial disorientation, the false horizon and autokinesis, are concerned with the visual system.

False Horizon

A sloping cloud formation, an obscured horizon, an aurora borealis, a dark scene spread with ground lights and stars, and certain geometric patterns of ground lights can provide inaccurate visual information, or **false horizon**, for aligning the aircraft correctly with the actual horizon. The disoriented pilot may place the aircraft in a dangerous attitude.

Autokinesis

In the dark, a stationary light will appear to move about when stared at for many seconds. The disoriented pilot could lose control of the aircraft in attempting to align it with the false movements of this light, called **autokinesis**.

Postural

The postural system sends signals from the skin, joints, and muscles to the brain that are interpreted in relation to the Earth's gravitational pull. These signals determine posture. Inputs from each movement update the body's position to the brain on a constant basis. "Seat of the pants" flying is largely dependent upon these signals. Used in conjunction with visual and vestibular clues, these sensations can be fairly reliable. However, because of the forces acting upon the body in certain flight situations, many false sensations can occur due to acceleration forces overpowering gravity. [Figure 1-4] These situations include uncoordinated turns, climbing turns, and turbulence.

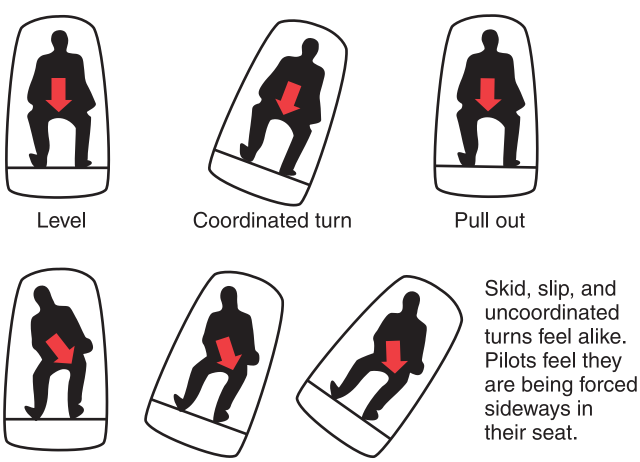


Figure 1-4. *Sensations from centrifugal force.*

Graveyard spiral: The illusion of the cessation of a turn while actually still in a prolonged coordinated, constant-rate turn, which can lead a disoriented pilot to a loss of control of the aircraft.

Somatogravic illusion: The feeling of being in a nose-up or nose-down attitude, caused by a rapid acceleration or deceleration while in flight situations that lack visual reference.

Inversion illusion: The feeling that the aircraft is tumbling backwards, caused by an abrupt change from climb to straight-and-level flight while in situations lacking visual reference.

Elevator illusion: The feeling of being in a climb or descent, caused by the kind of abrupt vertical accelerations that result from up- or downdrafts.

False horizon: Inaccurate visual information for aligning the aircraft caused by various natural and geometric formations that disorient the pilot from the actual horizon.

Autokinesis: Nighttime visual illusion that a stationary light is moving, which becomes apparent after several seconds of staring at the light.

Demonstrating Spatial Disorientation

There are a number of controlled aircraft maneuvers a pilot can perform to experiment with spatial disorientation. While each maneuver will normally create a specific illusion, any false sensation is an effective demonstration of disorientation. Thus, even if there is no sensation during any of these maneuvers, the absence of sensation is still an effective demonstration in that it shows the inability to detect bank or roll. There are several objectives in demonstrating these various maneuvers.

1. They teach pilots to understand the susceptibility of the human system to spatial disorientation.
2. They demonstrate that judgments of aircraft attitude based on bodily sensations are frequently false.
3. They can help to lessen the occurrence and degree of disorientation through a better understanding of the relationship between aircraft motion, head movements, and resulting disorientation.
4. They can help to instill a greater confidence in relying on flight instruments for assessing true aircraft attitude.

A pilot should not attempt any of these maneuvers at low altitudes, or in the absence of an instructor pilot or an appropriate safety pilot.

Climbing While Accelerating

With the pilot's eyes closed, the instructor pilot maintains approach airspeed in a straight-and-level attitude for several seconds, and then accelerates while maintaining straight-and-level attitude. The usual illusion during this maneuver, without visual references, will be that the aircraft is climbing.

Climbing While Turning

With the pilot's eyes still closed and the aircraft in a straight-and-level attitude, the instructor pilot now executes, with a relatively slow entry, a well-coordinated turn of about 1.5 positive G (approximately 50° bank) for 90°. While in the turn, without outside visual references and under the effect of the slight positive G, the usual illusion produced is that of a climb. Upon sensing the climb, the pilot should immediately open the eyes and see that a slowly established, coordinated turn produces the same feeling as a climb.

Demonstrating Spatial Disorientation—Safety Check
These demonstrations should never be conducted at low altitudes, or without an instructor pilot or appropriate safety pilot onboard.

Diving While Turning

This sensation can be created by repeating the previous procedure, with the exception that the pilot's eyes should be kept closed until recovery from the turn is approximately one-half completed. With the eyes closed, the usual illusion will be that the aircraft is diving.

Tilting to Right or Left

While in a straight-and-level attitude, with the pilot's eyes closed, the instructor pilot executes a moderate or slight skid to the left with wings level. The usual illusion is that the body is being tilted to the right.

Reversal of Motion

This illusion can be demonstrated in any of the three planes of motion. While straight-and-level, with the pilot's eyes closed, the instructor pilot smoothly and positively rolls the aircraft to approximately a 45°-bank attitude while maintaining heading and pitch attitude. The usual illusion is a strong sense of rotation in the opposite direction. After this illusion is noted, the pilot should open the eyes and observe that the aircraft is in a banked attitude.

Diving or Rolling Beyond the Vertical Plane

This maneuver may produce extreme disorientation. While in straight-and-level flight, the pilot should sit normally, either with eyes closed or gaze lowered to the floor. The instructor pilot starts a positive, coordinated roll toward a 30° or 40° angle of bank. As this is in progress, the pilot should tilt the head forward, look to the right or left, then immediately return the head to an upright position. The instructor pilot should time the maneuver so the roll is stopped just as the pilot returns his/her head upright. An intense disorientation is usually produced by this maneuver, with the pilot experiencing the sensation of falling downwards into the direction of the roll.

In the descriptions of these maneuvers, the instructor pilot is doing the flying, but having the pilot do the flying can also make a very effective demonstration. The pilot should close his/her eyes and tilt the head to one side. The instructor pilot tells the pilot what control inputs to perform. The pilot then attempts to establish the correct attitude or control input with eyes still closed and head still tilted. While it is clear the pilot has no idea of the actual attitude, he/she will react to what the senses are saying. After a short time, the pilot will become disoriented and the instructor pilot then tells the pilot to look up and recover. The benefit of this exercise is the pilot actually experiences the disorientation while flying the aircraft.

Coping with Spatial Disorientation

Pilots can take action to prevent illusions and their potentially disastrous consequences if they:

1. Understand the causes of these illusions and remain constantly alert for them.
2. Always obtain preflight weather briefings.
3. Do not continue flight into adverse weather conditions or into dusk or darkness unless proficient in the use of flight instruments.
4. Ensure that when outside visual references are used, they are reliable, fixed points on the Earth's surface.
5. Avoid sudden head movement, particularly during takeoffs, turns, and approaches to landing.
6. Remember that illness, medication, alcohol, fatigue, sleep loss, and mild hypoxia is likely to increase susceptibility to spatial disorientation.
7. Most importantly, become proficient in the use of flight instruments and rely upon them.

The sensations, which lead to illusions during instrument flight conditions, are normal perceptions experienced by pilots. These undesirable sensations cannot be completely prevented, but through training and awareness, pilots can ignore or suppress them by developing absolute reliance on the flight instruments. As pilots gain proficiency in instrument flying, they become less susceptible to these illusions and their effects.

Practice Makes Proficient
Through training and awareness in developing absolute reliance on the instruments, pilots can reduce their susceptibility to disorienting illusions.

Optical Illusions

Of the senses, vision is the most important for safe flight. However, various terrain features and atmospheric conditions can create **optical illusions**. These illusions are primarily associated with landing. Since pilots must transition from reliance on instruments to visual cues outside the cockpit for landing at the end of an instrument approach, it is imperative they are aware of the potential problems associated with these illusions, and take appropriate corrective action. The major illusions leading to landing errors are described below.

Runway Width Illusion

A narrower-than-usual runway can create an illusion the aircraft is at a higher altitude than it actually is, especially when runway length-to-width relationships are comparable. [Figure 1-5A] The pilot who does not recognize this illusion will fly a lower approach, with the risk of striking objects along the approach path or landing short. A wider-than-usual runway can have the opposite effect, with the risk of leveling out high and landing hard, or overshooting the runway.

Runway and Terrain Slopes Illusion

An upsloping runway, upsloping terrain, or both, can create an illusion the aircraft is at a higher altitude than it actually is. [Figure 1-5B] The pilot who does not recognize this illusion will fly a lower approach. Downsloping runways and downsloping approach terrain can have the opposite effect.

Featureless Terrain Illusion

An absence of surrounding ground features, as in an overwater approach, over darkened areas, or terrain made featureless by snow, can create an illusion the aircraft is at a higher altitude than it actually is. This illusion, sometimes referred to as the "black hole approach," causes pilots to fly a lower approach than is desired.

Water Refraction

Rain on the windscreen can create an illusion of being at a higher altitude due to the horizon appearing lower than it is. This can result in the pilot flying a lower approach.

Optical illusion: *(in aircraft flight)* A misleading visual image of features on the ground associated with landing, which causes a pilot to misread the spatial relationships between the aircraft and the runway.

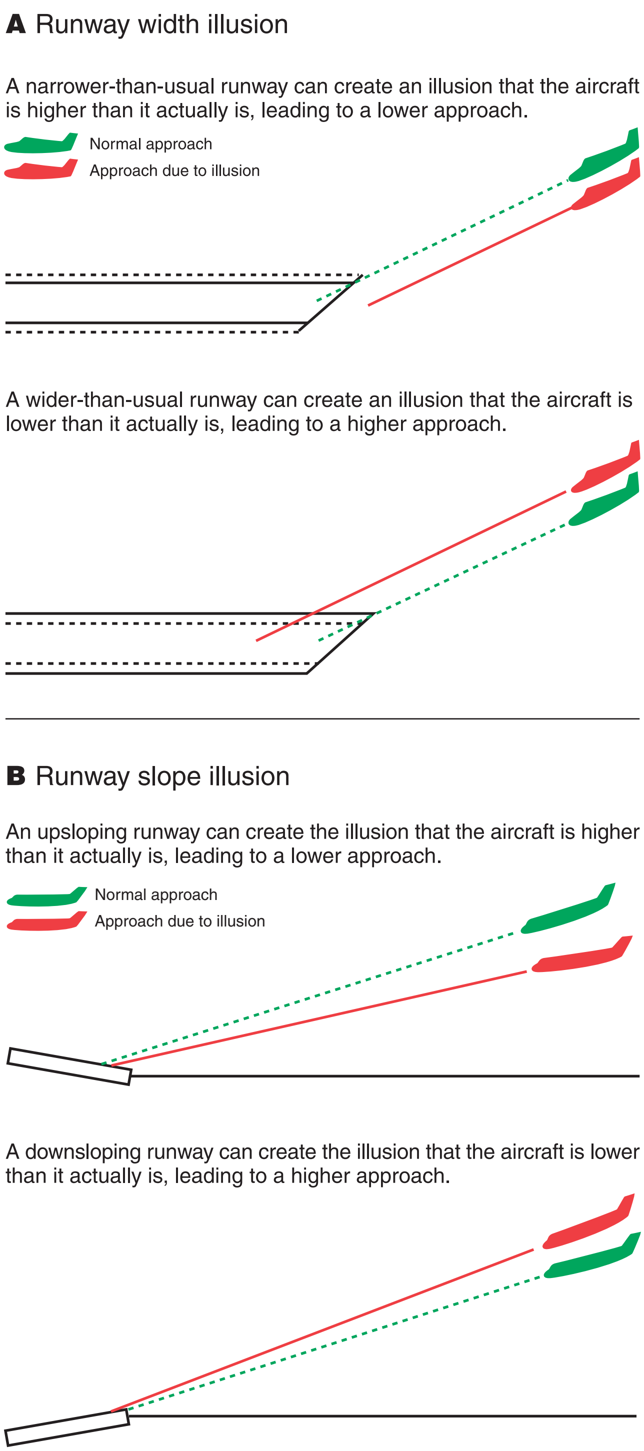


Figure 1-5. *Runway width and slope illusions.*

Haze

Atmospheric haze can create an illusion of being at a greater distance from the runway. As a result, the pilot will have a tendency to be high on the approach. Conversely, extremely clear air can give the pilot the illusion of being closer than he/she actually is, resulting in a long, low approach. The diffusion of light due to water particles can adversely affect depth perception. The lights and terrain features normally used to gauge height during landing become less effective for the pilot.

Fog

Penetration of fog can create an illusion of pitching up. Pilots who do not recognize this illusion will often steepen the approach quite abruptly.

Ground Lighting Illusions

Lights along a straight path, such as a road, and even lights on moving trains can be mistaken for runway and approach lights. Bright runway and approach lighting systems, especially where few lights illuminate the surrounding terrain, may create the illusion of less distance to the runway. The pilot who does not recognize this illusion will often fly a higher approach.

How to Prevent Landing Errors Due to Visual Illusions

Pilots can take action to prevent these illusions and their potentially hazardous consequences if they:

1. Anticipate the possibility of visual illusions during approaches to unfamiliar airports, particularly at night or in adverse weather conditions. Consult airport diagrams and the *Airport/Facility Directory* (A/FD) for information on runway slope, terrain, and lighting.
2. Make frequent reference to the altimeter, especially during all approaches, day and night.
3. If possible, conduct aerial visual inspection of unfamiliar airports before landing.
4. Use **Visual Approach Slope Indicator (VASI)** or **Precision Approach Path Indicator (PAPI)** systems for a visual reference, or an electronic glide slope, whenever they are available.

Visual Approach Slope Indicator (VASI): A system of lights arranged to provide visual descent guidance information during the approach to the runway. A pilot on the correct glide slope will see red lights over white lights.

Precision Approach Path Indicator (PAPI): Similar to the VASI but consisting of one row of lights in two- or four-light systems. A pilot on the correct glide slope will see two white lights and two red lights.

5. Utilize the visual descent point (VDP) found on many nonprecision instrument approach procedure charts.
6. Recognize that the chances of being involved in an approach accident increase when some emergency or other activity distracts from usual procedures.
7. Maintain optimum proficiency in landing procedures.

Vision Under Dim and Bright Illumination

Under conditions of dim illumination, aeronautical charts and aircraft instruments can become unreadable unless adequate cockpit lighting is available. In darkness, vision becomes more sensitive to light; this process is called **dark adaptation**. Although exposure to total darkness for at least 30 minutes is required for complete dark adaptation, a pilot can achieve a moderate degree of dark adaptation within 20 minutes under dim red cockpit lighting. Red light distorts colors, especially on aeronautical charts, and makes it very difficult for the eyes to focus on objects inside the aircraft. Pilots should use it only where optimum outside night vision capability is necessary. White cockpit lighting should be available when needed for map and instrument reading, especially under IMC conditions.

Dark adaptation is impaired by exposure to cabin pressure altitudes above 5,000 feet, carbon monoxide inhaled through smoking and from exhaust fumes, deficiency of Vitamin A in the diet, and by prolonged exposure to bright sunlight. Since any degree of dark adaptation is lost within a few seconds of viewing a bright light, pilots should close one eye when using a light to preserve some degree of night vision. During night flights in the vicinity of lightning, cockpit lights should be turned up to help prevent loss of night vision due to the bright flashes.

Physiological and Psychological Factors

Several factors can affect the pilot, either physiologically or psychologically, to the point where the safety of a flight can be severely compromised. These factors are stress, medical, alcohol, and fatigue. Any of these factors, individually or in combination, can significantly degrade the pilot's decision-making or flying abilities, both in the flight planning phase and in flight.

Stress

Stress is the body's response to demands placed upon it. These demands can be either pleasant or unpleasant in nature. The causes of stress for a pilot can range from unexpected weather or mechanical problems while in flight, to personal issues totally unrelated to flying. Stress is an inevitable and necessary part of life; it adds motivation to life and heightens a pilot's response to meet any challenge. The effects of stress are cumulative, and there is a limit to a pilot's adaptive nature. This limit, the stress tolerance level, is based on a pilot's ability to cope with the situation.

At first, some amount of stress can be desirable and can actually improve performance. Higher stress levels, particularly over long periods of time, can adversely affect performance. Performance will generally increase with the onset of stress, but will peak and then begin to fall off rapidly as stress levels exceed the ability to cope. [Figure 1-6A]

At the lower stress levels, boredom is followed by optimal performance at the moderate stress levels, then followed ultimately by overload and panic at the highest stress levels. At this point, a pilot's performance begins to decline and judgment deteriorates. Complex or unfamiliar tasks require higher levels of performance than simple or overlearned tasks. Complex or unfamiliar tasks are also more subject to the adverse effects of increasing stress than simple or familiar tasks. [Figure 1-6B]

The indicators of excessive stress often show as three types of symptoms: (1) emotional, (2) physical, and (3) behavioral. These symptoms depend upon whether aggression is focused inward or outward. Individuals who typically turn their aggressive feelings inward often demonstrate the emotional symptoms of depression, preoccupation, sadness, and withdrawal. Individuals who typically take out their frustration on other people or objects exhibit few physical symptoms. Emotional symptoms may surface as over-compensation, denial, suspicion, paranoia, agitation, restlessness, defensiveness, excess sensitivity to criticism, argumentativeness, arrogance, and hostility. Pilots need to learn to recognize the symptoms of stress as they begin to occur within themselves.

Dark adaptation: Physical and chemical adjustments of the eye that make vision possible in relative darkness.

Stress: The body's response to demands placed upon it.

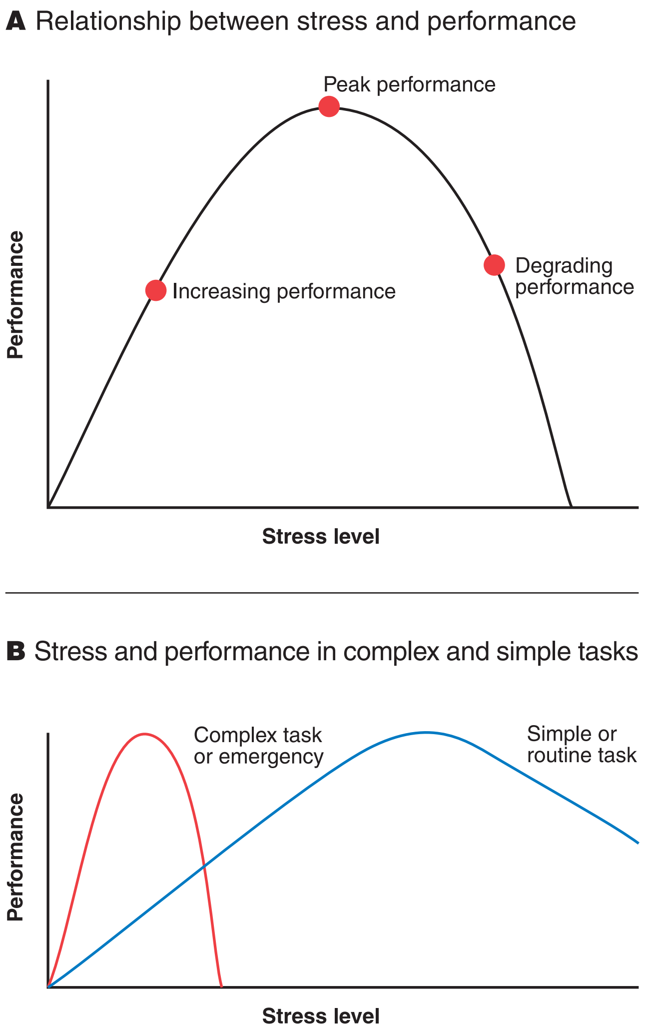


Figure 1-6. *Stress and performance.*

There are many techniques available that can help reduce stress in life or help people cope with it better. Not all of the following ideas may be the solution, but some of them should be effective.

1. Become knowledgeable about stress.
2. Take a realistic self-assessment.
3. Take a systematic approach to problem solving.
4. Develop a lifestyle that will buffer against the effects of stress.
5. Practice behavior management techniques.
6. Establish and maintain a strong support network.

Good cockpit stress management begins with good life stress management. Many of the stress-coping techniques practiced for life stress management are not usually practical in flight. Rather, pilots must condition themselves to relax and think rationally when stress appears. The following checklist outlines some methods of cockpit stress management.

1. Avoid situations that distract from flying the aircraft.
2. Reduce workload to reduce stress levels. This will create a proper environment in which to make good decisions.
3. If an emergency does occur, be calm. Think for a moment, weigh the alternatives, then act.
4. Become thoroughly familiar with the aircraft, its operation, and emergency procedures. Also, maintain flight proficiency to build confidence.
5. Know and respect personal limits.
6. Do not allow small mistakes to be distractions during flight; rather, review and analyze them after landing.
7. If flying adds stress, either stop flying or seek professional help to manage stress within acceptable limits.

Medical Factors

A "go/no-go" decision is made before each flight. The pilot should not only preflight check the aircraft, but also his/herself before every flight. As a pilot you should ask yourself, "Could I pass my medical examination right now?" If you cannot answer with an absolute "yes," then you should not fly. This is especially true for pilots embarking on flights in IMC. Instrument flying can be much more demanding than flying in VMC, and peak performance is critical for the safety of flight.

Pilot performance can be seriously degraded by both prescribed and over-the-counter medications, as well as by the medical conditions for which they are taken. Many medications, such as tranquilizers, sedatives, strong pain relievers, and cough-suppressants, have primary effects that may impair judgment, memory, alertness, coordination, vision, and the ability to make calculations. Others, such as antihistamines, blood pressure drugs, muscle relaxants, and agents to control diarrhea and motion sickness, have side effects that may impair the same critical functions. Any medication that depresses the nervous system, such as a sedative, tranquilizer, or antihistamine, can make a pilot much more susceptible to hypoxia.

Title 14 of the Code of Federal Regulations (14 CFR) prohibits pilots from performing crewmember duties while using any medication that affects the faculties in any way contrary to safety. The safest rule is not to fly as a crewmember while taking any medication, unless approved to do so by the Federal Aviation Administration (FAA). If there is any doubt regarding the effects of any medication, consult an Aviation Medical Examiner (AME) before flying.

Alcohol

14 CFR part 91 prohibits pilots from performing crewmember duties within 8 hours after drinking any alcoholic beverage or while under the influence. Extensive research has provided a number of facts about the hazards of alcohol consumption and flying. As little as one ounce of liquor, one bottle of beer, or four ounces of wine can impair flying skills and render a pilot much more susceptible to disorientation and **hypoxia**. Even after the body completely metabolizes a moderate amount of alcohol, a pilot can still be impaired for many hours. There is simply no way of increasing the metabolism of alcohol or alleviating a hangover.

Fatigue

Fatigue is one of the most treacherous hazards to flight safety, as it may not be apparent to a pilot until serious errors are made. Fatigue can be either acute (short-term) or chronic (long-term). A normal occurrence of everyday living, acute fatigue is the tiredness felt after long periods of physical and mental strain, including strenuous muscular effort, immobility, heavy mental workload, strong emotional pressure, monotony, and lack of sleep. Acute fatigue is prevented by adequate rest, regular exercise, and proper nutrition. Chronic fatigue occurs when there is not enough time for a full recovery from repeated episodes of acute fatigue. Recovery from chronic fatigue requires a prolonged period of rest. In either case, unless adequate precautions are taken, personal performance could be impaired and adversely affect pilot judgment and decision making.

Hypoxia: A state of oxygen deficiency in the body sufficient to impair functions of the brain and other organs.

IMSAFE Checklist

The following checklist, IMSAFE, is intended for a pilot's personal preflight use. A quick check of the items on this list can help the pilot make a good self-evaluation prior to any flight. If the answer to any of the checklist questions is yes, then the pilot should consider not flying.

Illness—Do I have any symptoms?

Medication—Have I been taking prescription or over-the-counter drugs?

Stress—Am I under psychological pressure from the job? Do I have money, health, or family problems?

Alcohol—Have I been drinking within 8 hours? Within 24 hours?

Fatigue—Am I tired and not adequately rested?

Eating—Have I eaten enough of the proper foods to keep adequately nourished during the entire flight?

Aeronautical Decision Making

Aeronautical decision making (ADM) is a systematic approach to the mental process used by pilots to consistently determine the best course of action in response to a given set of circumstances. ADM builds upon the foundation of conventional decision making, but enhances the process to decrease the probability of pilot error. ADM provides a structure to analyze changes that occur during a flight and determine how these changes might affect a flight's safe outcome.

The ADM process addresses all aspects of decision making in the cockpit and identifies the steps involved in good decision making. These steps are:

1. Identifying personal attitudes hazardous to safe flight.
2. Learning behavior modification techniques.
3. Learning how to recognize and cope with stress.
4. Developing risk assessment skills.
5. Using all resources.
6. Evaluating the effectiveness of one's ADM skills.

Aeronautical decision making (ADM): A systematic approach to the mental process used by pilots to consistently determine the best course of action in response to a given set of circumstances.

Figure 1-7A
Conventional decision making process

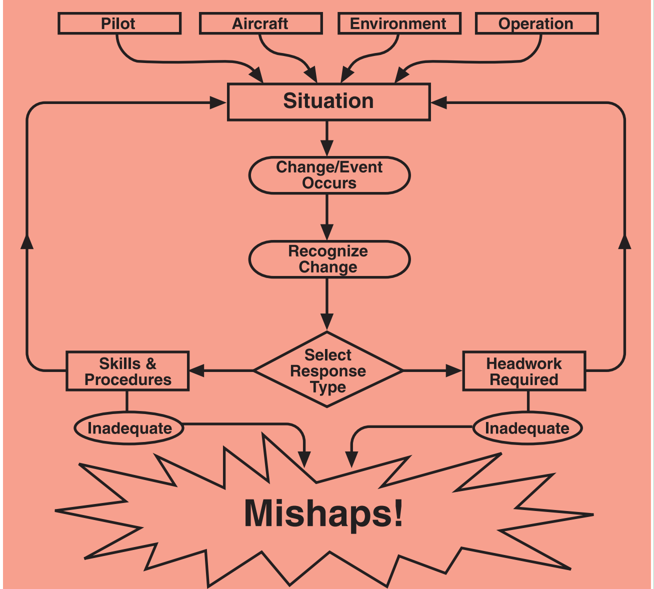


Figure 1-7B
Aeronautical decision making process

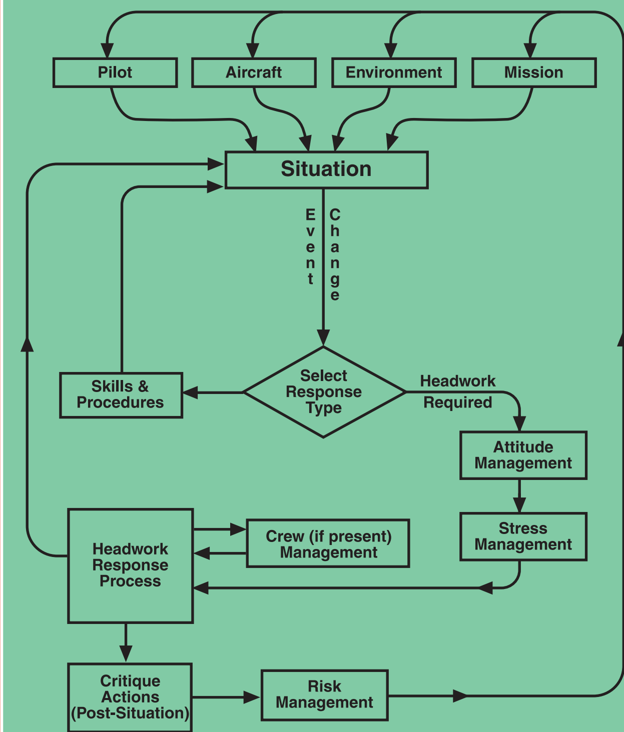


Figure 1-7C
The DECIDE Model

1. **Detect**. The decision maker detects the fact that change has occurred.
2. **Estimate**. The decision maker estimates the need to counter or react to the change.
3. **Choose**. The decision maker chooses a desirable outcome (in terms of success) for the flight.
4. **Identify**. The decision maker identifies actions which could successfully control the change.
5. **Do**. The decision maker takes the necessary action.
6. **Evaluate**. The decision maker evaluates the effect(s) of his/her action countering the change.

Figure 1-7. *Decision making.*

In conventional decision making, the need for a decision is triggered by recognition that something has changed or an expected change did not occur. Recognition of the change, or nonchange, is a vital step in any decision making process. Not noticing the change in the situation can lead directly to a mishap. [Figure 1-7A] The change indicates that an appropriate response or action is necessary in order to modify the situation (or, at least, one of the elements that comprise it) and bring about a desired new situation. Therefore, **situational awareness** is the key to successful and safe decision making. At this point in the process, the pilot is faced with a need to evaluate the entire range of possible responses to the detected change and to determine the best course of action.

Situational awareness: Knowing where you are in regard to location, air traffic control, weather, regulations, aircraft status, and other factors that may affect flight.

Figure 1-7B illustrates the ADM process, how this process expands conventional decision making, shows the interactions of the ADM steps, and how these steps can produce a safe outcome. Starting with the recognition of change, and following with an assessment of alternatives, a decision to act or not act is made, and the results are monitored. Pilots can use ADM to enhance their conventional decision making process because it: (1) increases their awareness of the importance of attitude in decision making; (2) teaches the ability to search for and establish relevance of information; (3) increases their motivation to choose and execute actions that ensure safety in the situational timeframe.

The DECIDE Model

A tool to use in making good aeronautical decisions is the DECIDE Model. [Figure 1-7C] The DECIDE Model is a six-step process intended to provide the pilot with a logical way of approaching decision making. The six elements of the DECIDE Model represent a continuous loop process to assist a pilot in the decision making when faced with a change in a situation that requires judgment. The model is primarily focused on the intellectual component, but can have an impact on the motivational component of judgment as well. If a pilot continually uses the DECIDE Model in all decision making, it becomes very natural and could result in better decisions being made under all types of situations.

Hazardous Attitudes and Antidotes

Research has identified five **hazardous attitudes** that can affect a pilot's judgment, as well as antidotes for each of these five attitudes. ADM addresses the following:

1. Anti-authority ("Don't tell me!"). This attitude is found in people who do not like anyone telling them what to do. They may be resentful of having someone tell them what to do or may regard rules, regulations, and procedures as silly or unnecessary. However, it is always your prerogative to question authority if you feel it is in error.
2. Impulsivity ("Do something quickly!"). This attitude is found in people who frequently feel the need to do something—anything—immediately. They do not stop to think about what they are about to do, they do not select the best alternative, and they do the first thing that comes to mind.
3. Invulnerability ("It won't happen to me!"). Many people feel that accidents happen to others, but never to them. They know accidents can happen, and they know that anyone can be affected. They never really feel or believe that they will be personally involved. Pilots who think this way are more likely to take chances and increase risk.
4. Macho ("I can do it!"). Pilots who are always trying to prove that they are better than anyone else are thinking, "I can do it—I'll show them." Pilots with this type of attitude will try to prove themselves by taking risks in order to impress others. This pattern is characteristic in both men and women.
5. Resignation ("What's the use?"). These pilots do not see themselves as being able to make a great deal of difference in what happens to them. When things go well, the pilot is apt to think it is due to good luck. When things go badly, the pilot may feel that someone is out to get them, or attribute it to bad luck. The pilot will leave the action to others, for better or worse. Sometimes, such pilots will even go along with unreasonable requests just to be a "nice guy."

Hazardous attitudes, which contribute to poor pilot judgment, can be effectively counteracted by redirecting that hazardous attitude so that correct action can be taken. Recognition of hazardous thoughts is the first step toward neutralizing them. After recognizing a thought as hazardous, the pilot should label it as hazardous, then state the corresponding antidote. Antidotes should be memorized for each of the hazardous attitudes so they automatically come to mind when needed. Each hazardous attitude along with its appropriate antidote is shown in figure 1-8.

Hazardous Attitude	Antidote
Anti-authority: Don't tell me.	Follow the rules. They are usually right.
Impulsivity: Do something quicky.	Not so fast. Think first.
Invulnerability: It won't happen to me.	It could happen to me.
Macho: I can do it.	Taking chances is foolish.
Resignation: What's the use?	I'm not helpless. I can make a difference.

Figure 1-8. *The five antidotes.*

Hazardous attitudes: Five attitudes that contribute to poor pilot judgment while making decisions in flight: anti-authority, impulsivity, invulnerability, "macho," and resignation.

Crew/Cockpit Resource Management

Crew/cockpit resource management (CRM) is the effective use of all available resources; human resources, hardware, and information. While CRM is primarily focused on pilots operating in crew environments, many of the elements and concepts apply to single pilot operations.

Human Resources

Human resources include all groups routinely working with pilots to ensure flight safety. These groups include, but are not limited to: weather briefers, flightline personnel, maintenance personnel, crewmembers, pilots, and air traffic personnel. Pilots must recognize the need to seek enough information from these sources to make a valid decision. After all of the necessary information has been gathered, the pilot's decision must be passed on to those concerned, such as other aircraft, air traffic controllers, crewmembers, and passengers. The pilot may have to request assistance from others and be assertive to safely resolve some situations.

CRM focuses on communication skills, teamwork, task allocation, and decision making. The single pilot needs to be able to effectively communicate with air traffic controllers, maintenance personnel, dispatchers, and other pilots. Key components of the communication process are inquiry, advocacy, and assertion.

Pilots should understand the need to seek further information from others until satisfied they have the proper information to make the best decision. Once a pilot has gathered all pertinent information and made the appropriate decision, the pilot needs to advocate the solution to others, such as air traffic controllers, to ensure the safe outcome of the flight. Pilots need to understand they must be assertive when seeking appropriate resolutions to problems they face.

Hardware

Equipment in many of today's aircraft includes automated flight and navigation systems. These automatic systems, while providing relief from many routine cockpit tasks, present a different set of problems for pilots. Information from these systems needs to be continually monitored to ensure proper situational awareness.

Information Workload

Workloads need to be properly managed. The pilot flying in IMC is faced with many tasks, each with a different level of importance to the outcome of the flight. For example, a pilot preparing to execute an instrument approach to an airport needs to review the approach chart, prepare the aircraft for the approach and landing, complete checklists, obtain information from Automatic Terminal Information Service (ATIS) or air traffic control (ATC), and set the navigation radios and equipment.

The pilot who effectively manages his/her workload will complete as many of these tasks as early as possible to preclude the possibility of becoming overloaded by last minutes changes and communication priorities in the later, more critical stages of the approach. Figure 1-9 shows the margin of safety is at the minimum level during this stage of the approach. Routine tasks that have been delayed until the last minute can contribute to the pilot becoming overloaded and stressed, resulting in an erosion of performance.

By planning ahead, a pilot can effectively reduce workload during critical phases of flight. If a pilot enters the final phases of the instrument approach unprepared, the pilot should recognize the situation, abandon the approach, and try it again after becoming better prepared. Effective resource management includes recognizing hazardous situations and attitudes, decision making to promote good judgment and headwork, and managing the situation to ensure the safe outcome of the IFR flight.

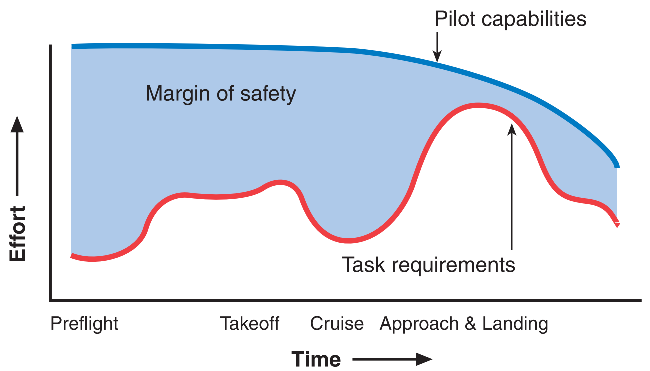


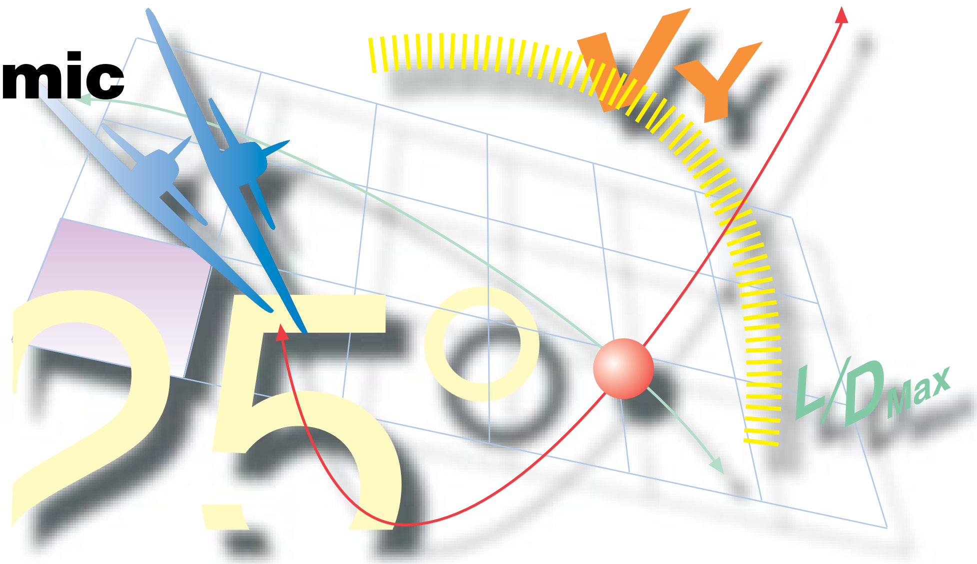
Figure 1-9. *The margin of safety.*

Crew/cockpit resource management (CRM): The effective use of all available resources—human resources, hardware, and information.

Keys to Communication
Inquiry—gather pertinent information.
Advocacy—promote a solution or decision.
Assertion—seek resolution with firm determination.

Chapter 2

Aerodynamic Factors



Introduction

This chapter outlines the factors affecting aircraft performance as a result of aerodynamics, including a review of basic aerodynamics, the atmosphere, and the effects of icing. Pilots need an understanding of these factors for a sound basis for prediction of aircraft response to control inputs, especially with regard to instrument approaches, while holding, and when operating at reduced airspeed in instrument meteorological conditions (IMC). Although these factors are important to the visual flight rules (VFR) pilot, they must be even more thoroughly understood by the pilot operating under instrument flight rules (IFR). Instrument pilots rely strictly on instrument indications to precisely control the aircraft; therefore, they must have a solid understanding of basic aerodynamic principles in order to make accurate judgments regarding aircraft control inputs.

Review of Basic Aerodynamics

As an instrument pilot, you must understand the relationship and differences between the aircraft's **flightpath**, **angle of attack**, and pitch attitude. Also, it is crucial to understand how the aircraft will react to various control and power changes because the environment in which instrument pilots fly has inherent hazards not found in visual flying. The basis for this understanding is found in the four forces and Newton's laws.

The Four Forces

The four basic forces acting upon an aircraft in flight are: lift, weight, thrust, and drag. The aerodynamic forces produced by the wing create lift. A byproduct of lift is **induced drag**. Induced drag combined with **parasite drag** (which is the sum of form drag, skin friction, and interference drag) produce the total drag on the aircraft. Thrust must equal total drag in order to maintain speed.

Lift must overcome the total weight of the aircraft, which is comprised of the actual weight of the aircraft plus the tail-down force used to control the aircraft's pitch attitude. Understanding how the aircraft's thrust/drag and lift/weight relationships affect its flightpath and airspeed is essential to proper interpretation of the aircraft's instruments, and to making proper control inputs.

Newton's First Law

Newton's First Law of Motion is the Law of Inertia, which states that a body in motion will remain in motion, in a straight line, unless acted upon by an outside force. Two outside forces are always present on an aircraft in flight: gravity and drag. Pilots use pitch and thrust controls to counter these forces to maintain the desired flightpath. If a pilot reduces power while in straight-and-level flight, the aircraft will slow. A reduction of lift will cause the aircraft to begin a descent. [Figure 2-1]

Flightpath: The line, course, or track along which an aircraft is flying or is intended to be flown.

Angle of attack: The acute angle formed between the chord line of an airfoil and the direction of the air that strikes the airfoil.

Induced drag: Caused by the same factors that produce lift, its amount varies inversely with airspeed. As airspeed decreases, the angle of attack must increase, and this increases induced drag.

Parasite drag: Caused by the friction of air moving over the structure, its amount varies directly with the airspeed. The higher the airspeed, the greater the parasite drag.

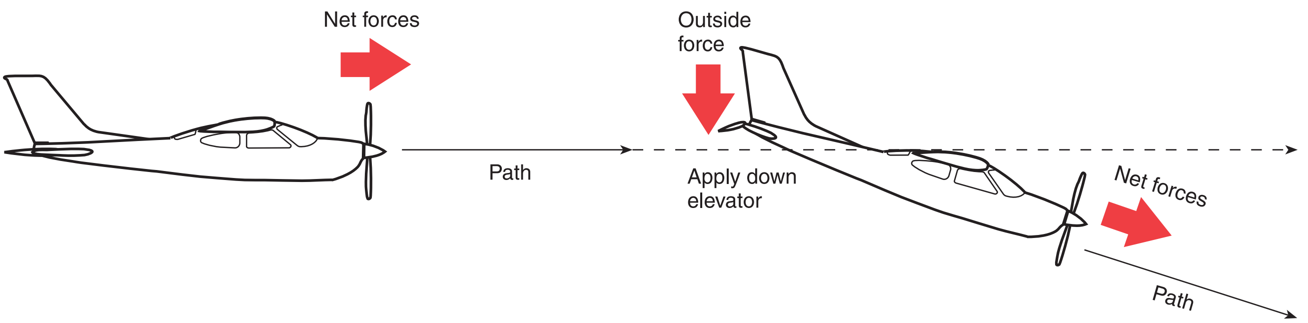


Figure 2-1. *Newton's First Law of Motion: the Law of Inertia.*

Newton's Second Law

Newton's Second Law of Motion is the Law of Momentum, which states that a body will accelerate in the same direction as the force acting upon that body, and the acceleration will be directly proportional to the net force and inversely proportional to the mass of the body. This law governs the aircraft's ability to change flightpath and speed, which are controlled by attitude (both pitch and bank) and thrust inputs. Speeding up, slowing down, entering climbs or descents, and turning are examples of accelerations that pilots control in everyday flight. [Figure 2-2]

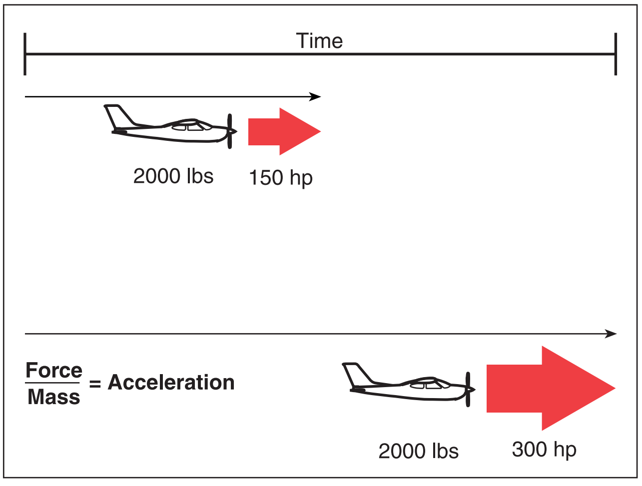


Figure 2-2. *Newton's Second Law of Motion: the Law of Momentum.*

Newton's Third Law

Newton's Third Law of Motion is the Law of Reaction, which states that for every action there is an equal and opposite reaction. As shown in figure 2-3, the *action* of the jet engine's thrust or the pull of the propeller lead to the *reaction* of the aircraft's forward motion. This law is also responsible for a portion of the lift that is produced by a wing, by the downward deflection of the airflow around it. This downward force of the **relative wind** results in an equal but opposite (upward) lifting force created by the airflow over the wing.

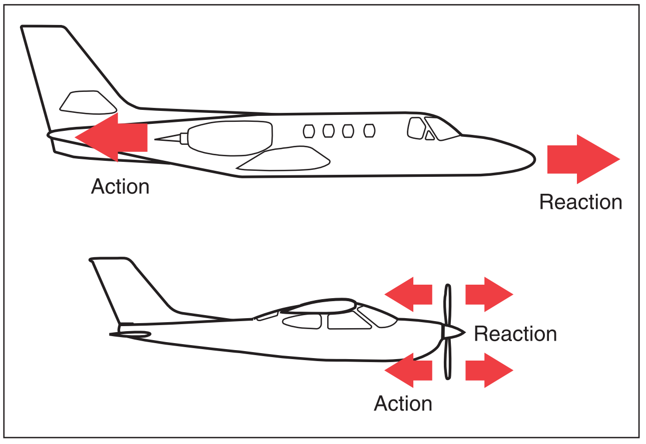


Figure 2-3. *Newton's Third Law of Motion: the Law of Reaction.*

Relative wind: The direction from which the wind meets an airfoil.

Atmosphere

Air density is a result of the relationship between temperature and pressure. This relationship is such that density is inversely related to temperature and directly related to pressure. For a constant pressure to be maintained as temperature increases, density must decrease, and vice versa. For a constant temperature to be maintained as pressure increases, density must increase, and vice versa. These relationships provide a basis for understanding instrument indications and aircraft performance.

Standard Atmosphere

The International Civil Aviation Organization (ICAO) established the ICAO Standard Atmosphere as a way of creating an international standard for reference and computations. Instrument indications and aircraft performance specifications are derived using this standard as a reference. Because the standard atmosphere is a derived set of conditions that rarely exist in reality, pilots need to understand how deviations from the standard affect both instrument indications and aircraft performance.

In the standard atmosphere, sea level pressure is 29.92" Hg and the temperature is 15 °C (59 °F). The standard lapse rate for pressure is approximately a 1" Hg decrease per 1,000 feet increase in altitude. The standard lapse rate for temperature is a 2 °C (3.6 °F) decrease per 1,000 feet increase, up to the tropopause. Since all aircraft performance is compared and evaluated in the environment of the standard atmosphere, all aircraft performance instrumentation is calibrated for the standard atmosphere. Because the actual operating conditions rarely, if ever, fit the standard atmosphere, certain corrections must apply to the instrumentation and aircraft performance.

Pressure Altitude

There are two measurements of the atmosphere that pilots must understand: pressure altitude and density altitude. Pressure altitude is the height above the standard datum pressure (29.92" Hg) and is used for standardizing altitudes for **flight levels (FL)** and for calculations involving aircraft performance. If the altimeter is set for 29.92" Hg, the altitude indicated is the pressure altitude.

Density Altitude

Density altitude is pressure altitude corrected for nonstandard temperatures, and is used for determining aerodynamic performance in the nonstandard atmosphere. Density altitude increases as the density decreases. Since density varies directly with pressure, and inversely with temperature, a wide range of temperatures may exist with a given pressure altitude, which allows the density to vary. However, a known density occurs for any one temperature and pressure altitude combination. The density of the air has a significant effect on aircraft and engine performance. Regardless of the actual altitude an aircraft is operating, its performance will be as though it were operating at an altitude equal to the existing density altitude.

Lift

Lift always acts in a direction perpendicular to the relative wind and to the lateral axis of the aircraft. The fact that lift is referenced to the wing, not to the Earth's surface, is the source of many errors in learning flight control. Lift is not always "up." Its direction relative to the Earth's surface changes as you maneuver the aircraft.

The magnitude of the force of lift is directly proportional to the density of the air, the area of the wings, and the airspeed. It also depends upon the type of wing and the angle of attack. Lift increases with an increase in angle of attack up to the stalling angle, at which point it decreases with any further increase in angle of attack. In conventional aircraft, lift is therefore controlled by varying the angle of attack (attitude) and thrust.

Pitch/Power Relationship

An examination of figure 2-4 provides insight into the relationship between pitch and power when it comes to controlling flightpath and airspeed. In order to maintain a constant lift, when the airspeed is reduced, the pitch must be increased. The pilot controls pitch through the elevators, which in effect controls the angle of attack. When back pressure is applied on the elevator control, the tail lowers and the nose rises, thus increasing the wing's angle of attack and lift.

Standard Atmosphere
ICAO Standard Atmosphere at sea level is 15 °C and 29.92" Hg. Most small aircraft manuals use this as a reference for their performance charts.

Safety Reminder
As density altitude increases, performance decreases—be aware on hot days at high altitudes.

Flight level (FL): A measure of altitude used by aircraft flying above 18,000 feet.

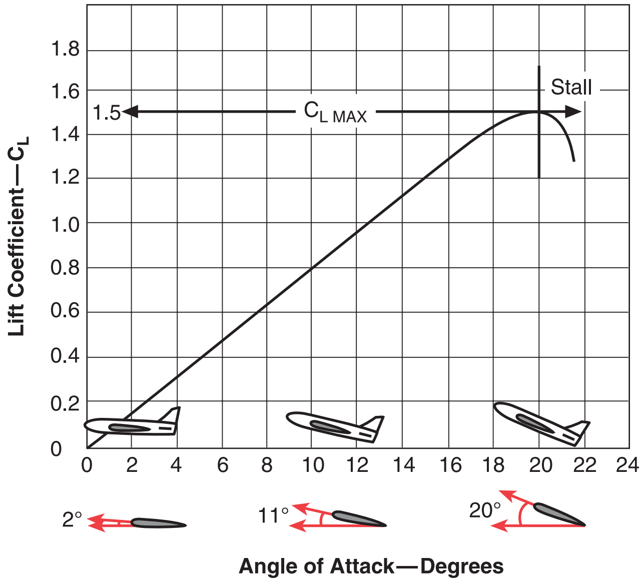


Figure 2-4. *Relationship of lift to angle of attack.*

Thrust is controlled by using the throttle to establish or maintain desired airspeeds. The most precise method of controlling flightpath is to use pitch control while simultaneously using power (thrust) to control airspeed. In order to maintain a constant lift, a change in pitch will require a change in power, and vice versa.

If you want the aircraft to accelerate while maintaining altitude, thrust must be increased to overcome drag. As the aircraft speeds up, lift is increased. To keep from gaining altitude, you must lower the pitch to reduce the angle of attack. If you want the aircraft to decelerate while maintaining altitude, thrust must be decreased. As the aircraft slows down, lift is reduced. Then you must increase the pitch in order to increase the angle of attack and maintain altitude.

Drag Curves

When induced drag and parasite drag are plotted on a graph, the total drag on the aircraft appears in the form of a "drag curve." [Figure 2-5] Graph A of figure 2-5 shows a curve based on thrust versus drag, which is primarily used for jet aircraft. Graph B of figure 2-5 is based on power versus drag, and it is used for propeller-driven aircraft. This chapter focuses on power versus drag charts for propeller-driven aircraft.

Understanding the drag curve can provide valuable insight into the various performance parameters and limitations of the aircraft. Because power must equal drag to maintain a steady airspeed, the curve can be either a drag curve or a "power-required curve." The power-required curve represents the amount of power needed to overcome drag in order to maintain a steady speed in level flight.

The propellers used on most reciprocating engines achieve peak propeller efficiencies in the range of 80 to 88 percent. As airspeed increases, the propeller efficiency will increase until it reaches its maximum. Any airspeed above this maximum point will cause a reduction in propeller efficiency. An engine that produces 160 horsepower will have only about 80 percent of that power converted into available horsepower, approximately 128 horsepower. This is the reason the thrust- and power-available curves change with speed.

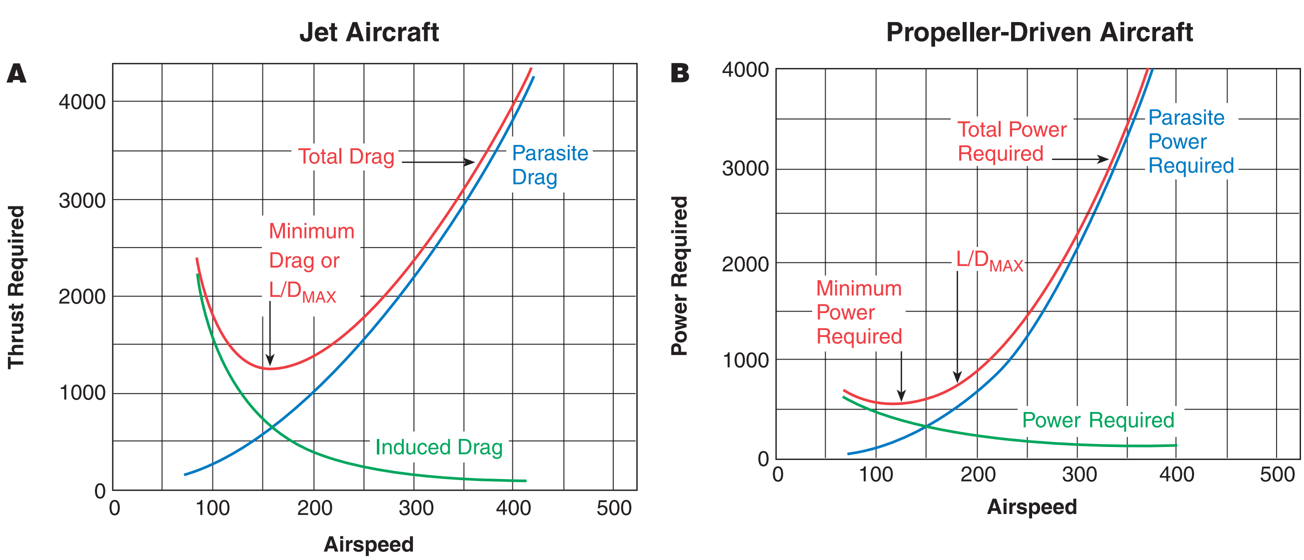


Figure 2-5. *Thrust and power required curves.*

Regions of Command

The drag curve also illustrates the two **regions of command**: the region of normal command, and the region of reversed command. The term "region of command" refers to the relationship between speed and the power required to maintain or change that speed. "Command" refers to the input the pilot must give in terms of power or thrust to maintain a new speed.

The "region of normal command" occurs where power must be added to increase speed. This region exists at speeds higher than the minimum drag point primarily as a result of parasite drag. The "region of reversed command" occurs where additional power is needed to maintain a slower airspeed. This region exists at speeds slower than the minimum drag point (L/D_{MAX} on the thrust-required curve, figure 2-5) and is primarily due to induced drag. Figure 2-6 shows how one power setting can yield two speeds, points 1 and 2. This is because at point 1 there is high induced drag and low parasite drag, while at point 2 there is high parasite drag and low induced drag.

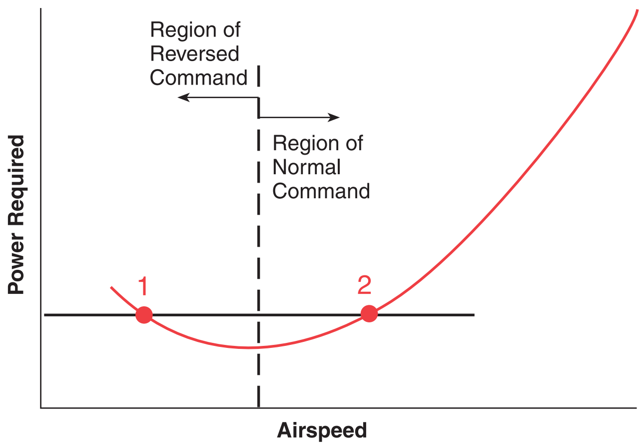


Figure 2-6. *Regions of command.*

Control Characteristics

Most flying is conducted in the region of normal command: for example, cruise, climb, and maneuvers. The region of reversed command may be encountered in the slow-speed phases of flight during takeoff and landing; however, for most general aviation aircraft, this region is very small and is below normal approach speeds.

Flight in the region of normal command is characterized by a relatively strong tendency of the aircraft to maintain the trim speed. Flight in the region of reversed command is characterized by a relatively weak tendency of the aircraft to maintain the trim speed. In fact, it is likely the aircraft will exhibit no inherent tendency to maintain the trim speed in this area. For this reason, you must give particular attention to precise control of airspeed when operating in the slow-speed phases of the region of reversed command.

Operation in the region of reversed command does not imply that great control difficulty and dangerous conditions will exist. However, it does amplify errors of basic flying technique—making proper flying technique and precise control of the aircraft very important.

Speed Stability

Normal Command

The characteristics of flight in the region of normal command are illustrated at point A on the curve in figure 2-7. If the aircraft is established in steady, level flight at point A, lift is equal to weight, and the power available is set equal to the power required. If the airspeed is increased with no changes to the power setting, a power deficiency exists. The aircraft will have the natural tendency to return to the initial speed to balance power and drag. If the airspeed is reduced with no changes to the power setting, an excess of power exists. The aircraft will have the natural tendency to speed up to regain the balance between power and drag. Keeping the aircraft in proper trim enhances this natural tendency. The **static longitudinal stability** of the aircraft tends to return the aircraft to the original trimmed condition.

An aircraft flying in steady, level flight at point C is in equilibrium. [Figure 2-7] If the speed were increased or decreased slightly, the aircraft would tend to remain at that speed. This is because the curve is relatively flat and a slight change in speed will not produce any significant excess or deficiency in power. It has the characteristic of neutral stability; the aircraft's tendency is to remain at the new speed.

Regions of command: The relationship between speed and the power required to maintain or change that speed in flight.

Static longitudinal stability: The aerodynamic pitching moments required to return the aircraft to the equilibrium angle of attack.

Slow Airspeed Safety Hint

Be sure to add power before pitching up while at slow airspeeds to prevent losing airspeed.

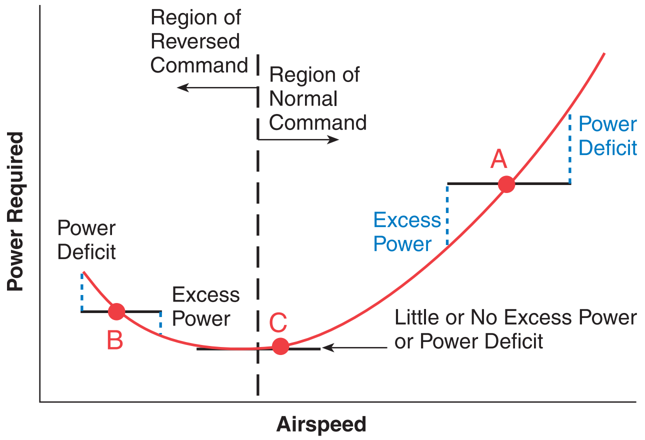


Figure 2-7. *Regions of speed stability.*

Reversed Command

The characteristics of flight in the region of reversed command are illustrated at point B on the curve in figure 2-7. If the aircraft is established in steady, level flight at point B, lift is equal to weight, and the power available is set equal to the power required. When the airspeed is increased greater than point B, an excess of power exists. This causes the aircraft to accelerate to an even higher speed. When the aircraft is slowed to some airspeed lower than point B, a deficiency of power exists. The natural tendency of the aircraft is to continue to slow to an even lower airspeed.

This tendency toward instability happens because the variation of excess power to either side of point B magnifies the original change in speed. Although the static longitudinal stability of the aircraft tries to maintain the original trimmed condition, this instability is more of an influence because of the increased induced drag due to the higher angles of attack in slow-speed flight.

Trim

A trim tab is a small, adjustable hinged surface, located on the trailing edge of the aileron, rudder, or elevator control surface. It is used to maintain balance in straight-and-level flight and during other prolonged flight conditions so the pilot does not have to hold pressure on the controls. This is accomplished by deflecting the tab in the direction opposite to that in which the primary control surface must be held.

Reversed Logic

In the region of reversed command, as you slow down you require more power.

The force of the airflow striking the tab causes the main control surface to be deflected to a position that will correct the unbalanced condition of the aircraft.

Because the trim tabs use airflow to function, trim is a function of speed. Any change in speed will result in the need to retrim the aircraft. A properly trimmed aircraft seeks to return to the original speed before the change. Therefore, it is very important for instrument pilots to keep the aircraft in constant trim. This will reduce the workload significantly and allow pilots to tend to other duties without compromising aircraft control.

Slow-Speed Flight

Anytime you are flying near the stalling speed or the region of reversed command, such as in final approach for a normal landing, the initial part of a go-around, or maneuvering in slow flight, you are operating in what is called slow-speed flight. It is characterized by high angles of attack and in many cases, the need for flaps or other high-lift devices.

Small Airplanes

Most small airplanes maintain a speed well in excess of 1.3 times V_{SO} on an instrument approach. An airplane with a stall speed of 50 knots (V_{SO}) has a normal approach speed of 65 knots. However, this same airplane may maintain 90 knots (1.8 V_{SO}) while on the final segment of an instrument approach. The landing gear will most likely be extended at the beginning of the descent to the minimum descent altitude, or upon intercepting the glide slope of the instrument landing system. The pilot may also select an intermediate flap setting for this phase of the approach. The airplane at this speed will have good positive speed stability, as represented by point A on figure 2-7. Flying at this point, you can make slight pitch changes without changing power settings, and accept minor speed changes knowing that when the pitch is returned to the initial setting, the speed will return to the original setting. This reduces your workload.

You would usually slow down to a normal landing speed when on a relatively short final. When you slow the airplane to 65 knots, 1.3 V_{SO}, the airplane will be close to point C. [Figure 2-7] At this point, precise control of the pitch and power becomes more crucial for maintaining the correct speed. Pitch and power coordination is necessary because the speed stability is relatively neutral—the speed tends to remain at the new value and not return to the original setting. In addition to the need for more precise airspeed control, you would normally change the aircraft's configuration by adding landing flaps. This configuration change means you must guard against unwanted pitch changes at a low altitude.

If you allow the speed to slow several knots, the airplane could enter the region of reversed command. At this point, the airplane could develop an unsafe sink rate and continue to lose speed if you do not take prompt, corrective action. Proper pitch and power coordination is critical in this region due to speed instability and the tendency of increased divergence from the desired speed.

Large Airplanes

Pilots of larger airplanes with higher stall speeds may find the speed they maintain on the instrument approach is near 1.3 V_{SO}, putting them near point C (in figure 2-7) the entire time the airplane is on the final approach segment. In this case, precise speed control is necessary throughout the approach. It may be necessary to overpower or underpower in relation to the target power setting in order to quickly correct for airspeed deviations.

For example, a pilot is on an instrument approach at 1.3 V_{SO}, a speed near L/D_{MAX}, and knows that a certain power setting will maintain that speed. The airplane slows several knots below the desired speed because of a slight reduction in the power setting. The pilot increases the power slightly, and the airplane begins to accelerate, but at a slow rate. Because the airplane is still in the "flat part" of the drag curve, this slight increase in power will not cause a rapid return to the desired speed. The pilot may need to increase the power higher than normally needed to maintain the new speed, allow the airplane to accelerate, then reduce the power to the setting that will maintain the desired speed.

Climbs

The ability for an aircraft to climb depends upon an excess power or thrust over what it takes to maintain equilibrium. Excess power is the available power over and above that required to maintain horizontal flight at a given speed. Although the terms power and thrust are sometimes used interchangeably (erroneously implying they are synonymous), distinguishing between the two is important when considering climb performance. **Work** is the product of a force moving through a distance and is usually independent of time. **Power** implies work rate or units of work per unit of time, and as such is a function of the speed at which the force is developed. **Thrust** also a function of work, means the force which imparts a change in the velocity of a mass.

For a given weight of the aircraft, the angle of climb depends on the difference between thrust and drag, or the excess thrust. When the excess thrust is zero, the inclination of the flightpath is zero, and the aircraft will be in steady, level flight. When thrust is greater than drag, the excess thrust will allow a climb angle depending on the amount of excess thrust. When thrust is less than drag, the deficiency of thrust will induce an angle of descent.

Acceleration in Cruise Flight

Aircraft accelerate in level flight because of an excess of power over what is required to maintain a steady speed. This is the same excess power used to climb. When you reach the desired altitude and lower the pitch to maintain that altitude, the excess power can now accelerate the aircraft to its cruise speed. Reducing power too soon after level-off will result in a longer period of time to accelerate.

Turns

Like any moving object, an aircraft requires a sideward force to make it turn. In a normal turn, this force is supplied by banking the aircraft in order to exert lift inward as well as upward. The force of lift is separated into two components at right angles to each other. [Figure 2-8] The upward-acting lift and the opposing weight together become the vertical lift component. The horizontally-acting lift and its opposing centrifugal force are the horizontal lift component, or centripetal force. This horizontal lift component is the sideward force that causes an aircraft to turn. The equal and opposite reaction to this sideward force is centrifugal force, which is merely an apparent force as a result of inertia.

The relationship between the aircraft's speed and bank angle to the rate and radius of turns is important for instrument pilots to understand. You can use this knowledge to properly estimate bank angles needed for certain rates of turn, or for figuring how much to lead when intercepting a course.

Work: A physical measurement of force used to produce movement.

Power (mechanical): Work done in a period of time.

Thrust (aerodynamic force): The forward aerodynamic force produced by a propeller, fan, or turbojet engine as it forces a mass of air to the rear, behind the aircraft.

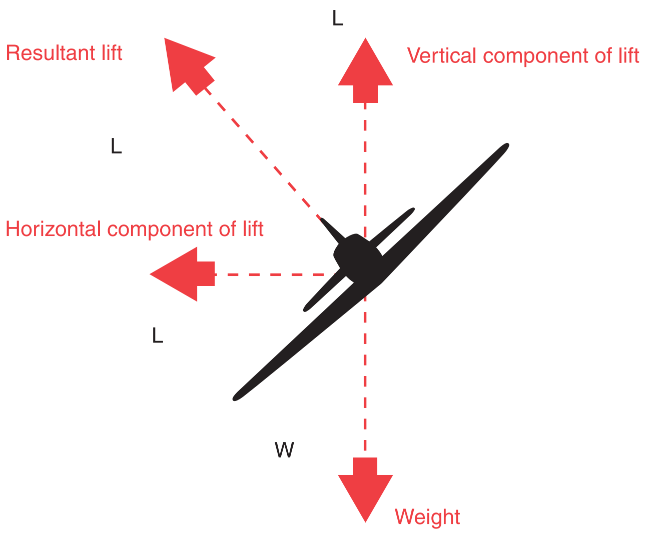


Figure 2-8. *Forces in a turn.*

Rate of Turn

The rate of turn, normally measured in degrees per second, is based upon a set bank angle at a set speed. If either one of these elements changes, then the rate of turn will change. If the aircraft increases its speed without changing the bank angle, then the rate of turn will decrease. Likewise, if the speed decreases without changing the bank angle, the rate of turn will increase.

Changing the bank angle without changing speed will also cause the rate of turn to change. Increasing the bank angle without changing speed will increase the rate of turn, while decreasing the bank angle will reduce the rate of turn.

The standard rate of turn, 3° per second, is used as the main reference for bank angle. Therefore, you must understand how the angle of bank will vary with speed changes, such as slowing down for holding or an instrument approach. Figure 2-9 shows the turn relationship with reference to a constant bank angle or a constant airspeed, and the effects on rate of turn and radius of turn.

Radius of Turn

The radius of turn will vary with changes in either speed or bank. If the speed is increased without changing the bank angle, the radius of turn will increase, and vice versa. If the speed is constant, increasing the bank angle will reduce the radius of turn, while decreasing the bank angle will increase the radius of turn. This means that intercepting a course at a higher speed will require more distance, and therefore, require a longer lead. If the speed is slowed considerably in preparation for holding or an approach, a shorter lead is needed than that required for cruise flight.

Coordination of Rudder and Aileron Controls

Anytime ailerons are used, **adverse yaw** is produced. This yaw causes the nose of the aircraft to initially move in the direction opposite of the turn. Correcting for this yaw with rudder, when entering and exiting turns is necessary for precise control of the aiplane when flying on instruments. You can tell if the turn is coordinated by checking the ball in the turn-and-slip indicator or the turn coordinator.

As you bank the wings to enter the turn, a portion of the wing's vertical lift becomes the horizontal component; therefore, without an increase in back pressure, the aircraft will lose altitude during the turn. The loss of vertical lift can be offset by increasing the pitch in one-half bar width increments. Trim may be used to relieve the control pressures; however, if used, it will have to be removed once the turn is complete.

In a slipping turn, the aircraft is not turning at the rate appropriate to the bank being used, and the aircraft falls to the inside of the turn. The aircraft is banked too much for the rate of turn, so the horizontal lift component is greater than the centrifugal force. A skidding turn results from excess of centrifugal force over the horizontal lift component, pulling the aircraft toward the outside of the turn. The rate of turn is too great for the angle of bank, so the horizontal lift component is less than the centrifugal force.

The ball instrument indicates the quality of the turn, and should be centered when the wings are banked. If the ball is out of its **cage** on the side toward the turn, the aircraft is slipping and you should add rudder pressure on that side to increase the rate of turn, and adjust the bank angle as required. If the ball is out of its cage on the side away from the turn, the aircraft is skidding and rudder pressure toward the turn should be relaxed or the bank angle increased. If the aircraft is properly rigged, the ball should be in the center when the wings are level; use rudder and/or aileron trim if available.

Adverse yaw: A flight condition at the beginning of a turn in which the nose of the aircraft starts to move in the direction opposite the direction the turn is being made.

Cage: The black markings on the ball instrument indicating its neutral position.

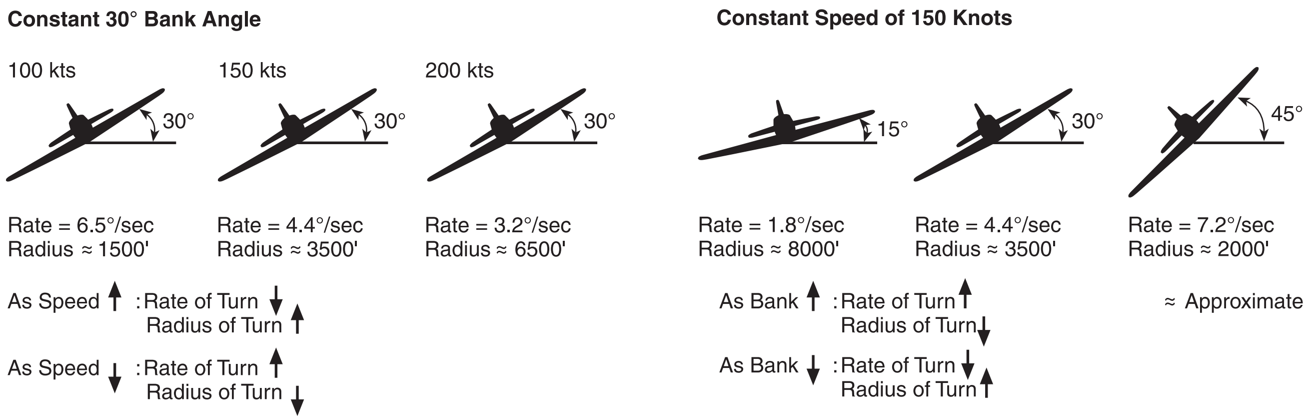


Figure 2-9. *Turns.*

The increase in induced drag (caused by the increase in angle of attack necessary to maintain altitude) will result in a minor loss of airspeed if the power setting is not changed. Accept this loss of airspeed—an attempt to maintain airspeed may divert your attention at a critical time.

Load Factor

Any force applied to an aircraft to deflect its flight from a straight line produces a stress on its structure; the amount of this force is termed **load factor**. A load factor is the ratio of the aerodynamic force on the aircraft to the gross weight of the aircraft (e.g., lift/weight). For example, a load factor of 3 means the total load on an aircraft's structure is three times its gross weight. When designing an aircraft, it is necessary to determine the highest load factors that can be expected in normal operation under various operational situations. These "highest" load factors are called "limit load factors."

Aircraft are placed in various categories, i.e., normal, utility, and acrobatic, depending upon the load factors they are designed to take. For reasons of safety, the aircraft must be designed to withstand certain maximum load factors without any structural damage.

The specified load may be expected in terms of aerodynamic forces, as in turns. In level flight in undisturbed air, the wings are supporting not only the weight of the aircraft, but centrifugal force as well. As the bank steepens, the horizontal lift component increases, centrifugal force increases, and the load factor increases. If the load factor becomes so great that an increase in angle of attack cannot provide enough lift to support the load, the wing stalls. Since the stalling speed increases directly with the square root of the load factor, you should be aware of the flight conditions during which the load factor can become critical. Steep turns at slow airspeed, structural ice accumulation, and vertical gusts in turbulent air can increase the load factor to a critical level.

Effects of Icing

One of the hazards to flight is aircraft icing. Pilots should be aware of the conditions conducive to icing, the types of icing, the effects of icing on aircraft control and performance, and the use and limitations of aircraft deice and anti-ice equipment.

Structural icing refers to the accumulation of ice on the exterior of the aircraft; induction icing affects the powerplant operation. Significant structural icing on an aircraft can cause aircraft control and performance problems. To reduce the probability of ice buildup on the unprotected areas of the aircraft, you should maintain at least the minimum airspeed for flight in sustained icing conditions. This airspeed will be listed in the Pilot's Operating Handbook/Airplane Flight Manual (POH/AFM).

Load factor: Lift to weight ratio.

The most hazardous aspect of structural icing is its aerodynamic effects. [Figure 2-10] Ice can alter the shape of an airfoil, which can cause control problems, change the angle of attack at which the aircraft stalls, and cause the aircraft to stall at a significantly higher airspeed. Ice can reduce the amount of lift an airfoil will produce and greatly increase drag. It can partially block or limit control surfaces which will limit or make control movements ineffective. Also, if the extra weight caused by ice accumulation is too great, the aircraft may not be able to become airborne and, if in flight, the aircraft may not be able to maintain altitude. Any accumulation of ice or frost should be removed before attempting flight.

Another hazard of structural icing is the possible uncommanded and uncontrolled roll phenomenon, referred to as roll upset, associated with severe in-flight icing. Pilots flying aircraft certificated for flight in known icing conditions should be aware that severe icing is a condition outside of the aircraft's certification icing envelope. Roll upset may be caused by airflow separation (aerodynamic stall) which induces self-deflection of the ailerons and loss of or degraded roll-handling characteristics. These phenomena can result from severe icing conditions without the usual symptoms of ice accumulation or a perceived aerodynamic stall.

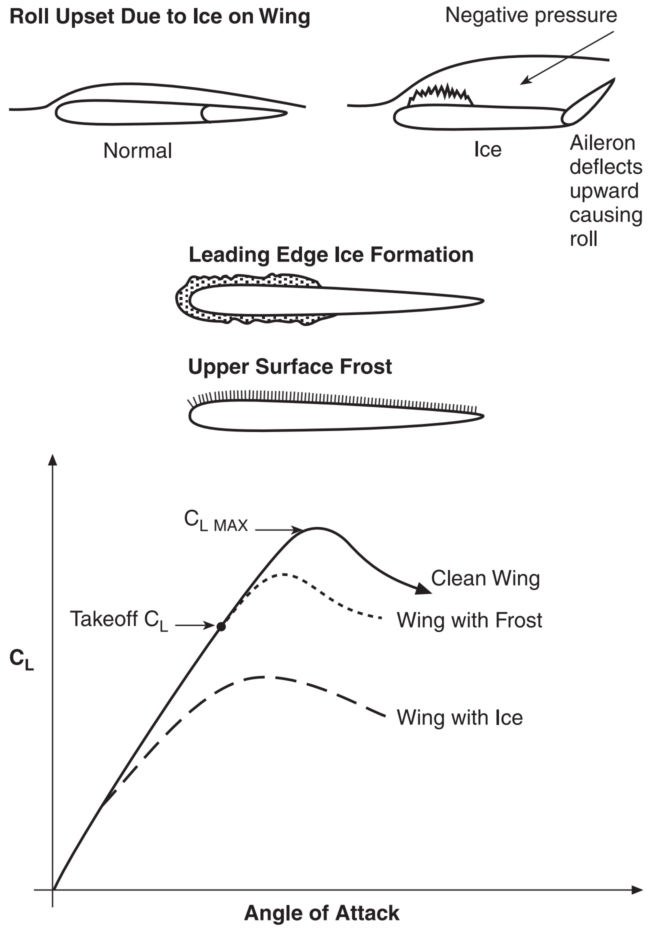
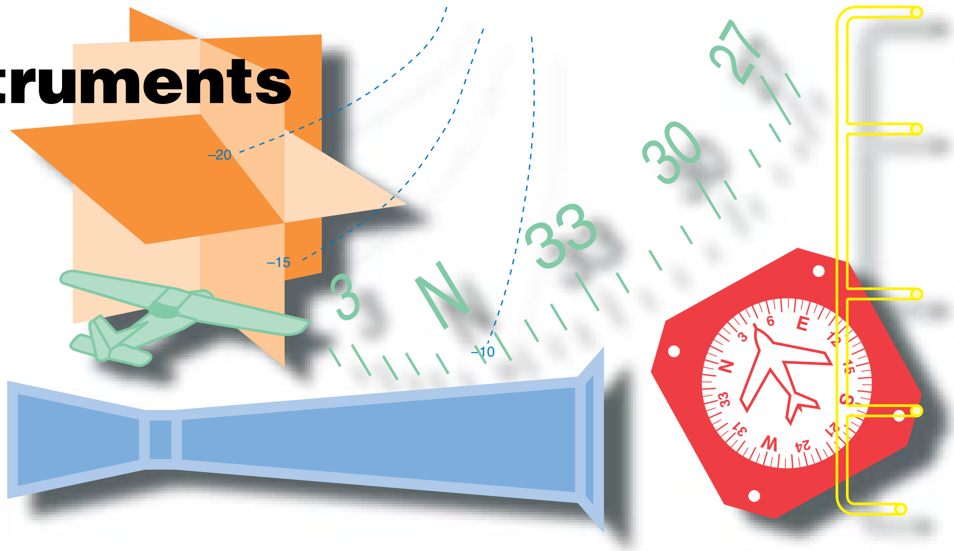


Figure 2-10. *Effect of ice and frost on lift.*

Chapter 3

Flight Instruments



Introduction

Aircraft became a practical means of transportation when accurate flight instruments freed the pilot from the necessity of maintaining visual contact with the ground. Safety was enhanced when all pilots with private or higher ratings were required to demonstrate their ability to maintain level flight and make safe turns without reference to the outside horizon.

The basic flight instruments required for operation under visual flight rules (VFR) are an airspeed indicator, an altimeter, and a magnetic direction indicator. In addition to these, operation under instrument flight rules (IFR) requires a gyroscopic rate-of-turn indicator, a slip-skid indicator, a sensitive altimeter adjustable for barometric pressure, a clock displaying hours, minutes, and seconds with a sweep-second pointer or digital presentation, a gyroscopic pitch-and-bank indicator (artificial horizon), and a gyroscopic direction indicator (directional gyro or equivalent).

Aircraft that are flown in instrument meteorological conditions (IMC) are equipped with instruments that provide attitude and direction reference, as well as radio navigation instruments that allow precision flight from takeoff to landing with limited or no outside visual reference.

The instruments discussed in this chapter are those required by Title 14 of the Code of Federal Regulations (14 CFR) part 91, and are organized into three groups: pitot-static instruments, compass systems, and gyroscopic instruments. The chapter concludes with a discussion of how to preflight these systems for IFR flight.

Pitot-Static Systems

Three basic pressure-operated instruments are found in most aircraft instrument panels. These are the sensitive altimeter, airspeed indicator (ASI), and vertical speed indicator (VSI). All three receive the pressures they measure from the aircraft pitot-static system.

Flight instruments depend upon accurate sampling of the ambient atmospheric pressure to determine the height and speed of movement of the aircraft through the air, both horizontally and vertically. This pressure is sampled at two or more locations outside the aircraft by the pitot-static system.

The pressure of the static, or still air, is measured at a flush port where the air is not disturbed. On some aircraft, this air is sampled by static ports on the side of the electrically heated **pitot-static head**, such as the one in figure 3-1. Other aircraft pick up the **static pressure** through flush ports on the side of

Pitot-static head: A combination pickup used to sample pitot pressure and static air pressure.

Static pressure: Pressure of the air that is still, or not moving, measured perpendicular to the surface of the aircraft.

the fuselage or the vertical fin. These ports are in locations proven by flight tests to be in undisturbed air, and they are normally paired, one on either side of the aircraft. This dual location prevents lateral movement of the aircraft from giving erroneous static pressure indications. The areas around the static ports may be heated with electric heater elements to prevent ice forming over the port and blocking the entry of the static air.

Pitot pressure, or impact air pressure, is taken in through an open-end tube pointed directly into the relative wind flowing around the aircraft. The pitot tube connects to the airspeed indicator, and the static ports deliver their pressure to the airspeed indicator, altimeter, and VSI. If the static ports should ice over, or in any other way become obstructed, the pilot is able to open a static-system alternate source valve to provide a static air pressure source from a location inside the aircraft. [Figure 3-2] This may cause an inaccurate indication on the pitot-static instrument. Consult the Pilot's Operating Handbook/Airplane Flight Manual (POH/AFM) to determine the amount of error.

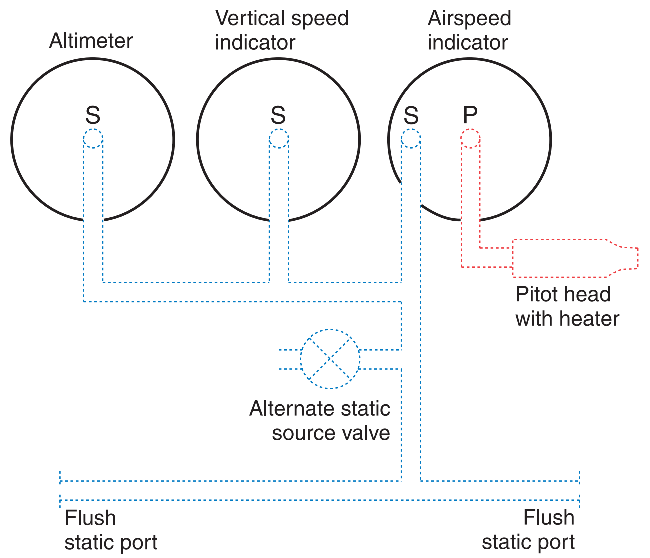


Figure 3-2. *A typical pitot-static system.*

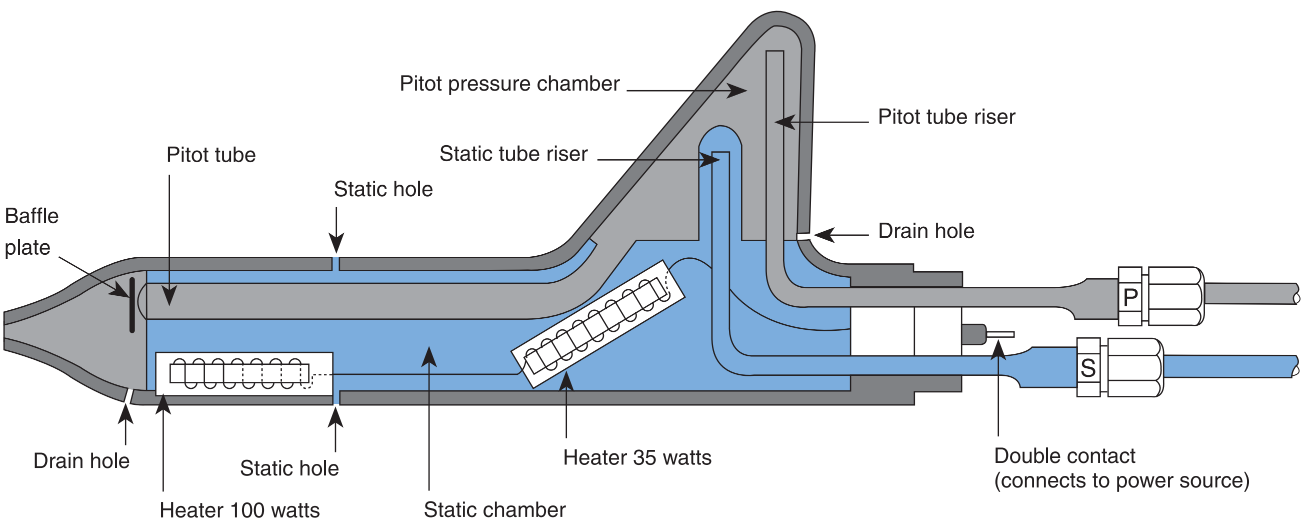


Figure 3-1. *A typical electrically heated pitot-static head.*

Pitot pressure: Ram air pressure used to measure airspeed.

Position Error

The static ports are located in a position where the air at their surface is as undisturbed as possible. But under some flight conditions, particularly at a high angle of attack with the landing gear and flaps down, the air around the static port may be disturbed to the extent that it can cause an error in the indication of the altimeter and airspeed indicator. Because of the importance of accuracy in these instruments, part of the certification tests for an aircraft is a check of **position error** in the static system.

The POH/AFM contains any corrections that must be applied to the airspeed for the various configurations of flaps and landing gear.

Pitot-Static Instruments

Sensitive Altimeter

A sensitive altimeter is an aneroid barometer that measures the absolute pressure of the ambient air and displays it in terms of feet or meters above a selected pressure level.

Principle of Operation

The sensitive element in a sensitive altimeter is a stack of evacuated, corrugated bronze aneroid capsules like those shown in figure 3-3. The air pressure acting on these aneroids tries to compress them against their natural springiness, which tries to expand them. The result is that their thickness changes as the air pressure changes. Stacking several aneroids increases the dimension change as the pressure varies over the usable range of the instrument.

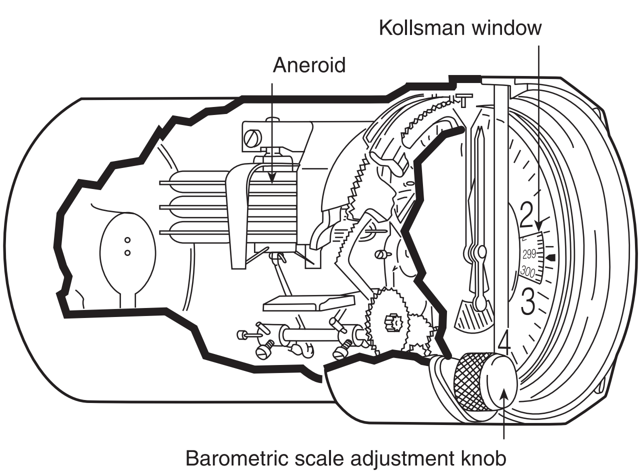


Figure 3-3. *Sensitive altimeter components.*

Position error: Error in the indication of the altimeter, ASI, and VSI caused by the air at the static system entrance not being absolutely still.

Below 10,000 feet, a striped segment is visible. Above this altitude, a mask begins to cover it, and above 15,000 feet, all of the stripes are covered. [Figure 3-4]

Another configuration of the altimeter is the drum-type, like the one in figure 3-5. These instruments have only one pointer that makes one revolution for every 1,000 feet. Each number represents 100 feet, and each mark represents 20 feet. A drum, marked in thousands of feet, is geared to the mechanism that drives the pointer. To read this type of altimeter, first look at the drum to get the thousands of feet, and then at the pointer to get the feet and hundreds of feet.

Figure 3-4. *Three-pointer altimeter.*

Figure 3-5. *Drum-type altimeter.*

A sensitive altimeter is one with an adjustable barometric scale that allows you to set the reference pressure from which the altitude is measured. This scale is visible in a small window, called the **Kollsman window**. The scale is adjusted by a knob on the instrument. The range of the scale is from 28.00 to 31.00" Hg, or 948 to 1,050 millibars.

Rotating the knob changes both the barometric scale and the altimeter pointers in such a way that a change in the barometric scale of 1" Hg changes the pointer indication by 1,000 feet. This is the standard pressure lapse rate below 5,000 feet. When the barometric scale is adjusted to 29.92" Hg, or 1,013.2 millibars, the pointers indicate the pressure altitude. When you wish to display indicated altitude, adjust the barometric scale to the local altimeter setting. The instrument then indicates the height above the existing sea level pressure.

Altimeter Errors

A sensitive altimeter is designed to indicate standard changes from standard conditions, but most flying involves errors caused by nonstandard conditions, and you must be able to modify the indications to correct for these errors. There are two types of errors: mechanical and inherent.

A preflight check to determine the condition of an altimeter consists of setting the barometric scale to the altimeter setting transmitted by the local automated flight service station (AFSS). The altimeter pointers should indicate the surveyed elevation of the airport. If the indication is off more than 75 feet from the surveyed elevation, the instrument should be referred to a certificated instrument repair station for recalibration. Differences between ambient temperature and/or pressure will cause an erroneous indication on the altimeter.

Figure 3-6 shows the way nonstandard temperature affects an altimeter. When the aircraft is flying in air that is warmer than standard, the air is less dense and the pressure levels are farther apart. When the aircraft is flying at an indicated altitude of 5,000 feet, the pressure level for that altitude is higher than it would be in air at standard temperature, and the aircraft will be higher than it would be if the air were cooler.

If the air is colder than standard, it is denser, and the pressure levels are closer together. When the aircraft is flying at an indicated altitude of 5,000 feet, its true altitude is lower than it would be if the air were warmer.

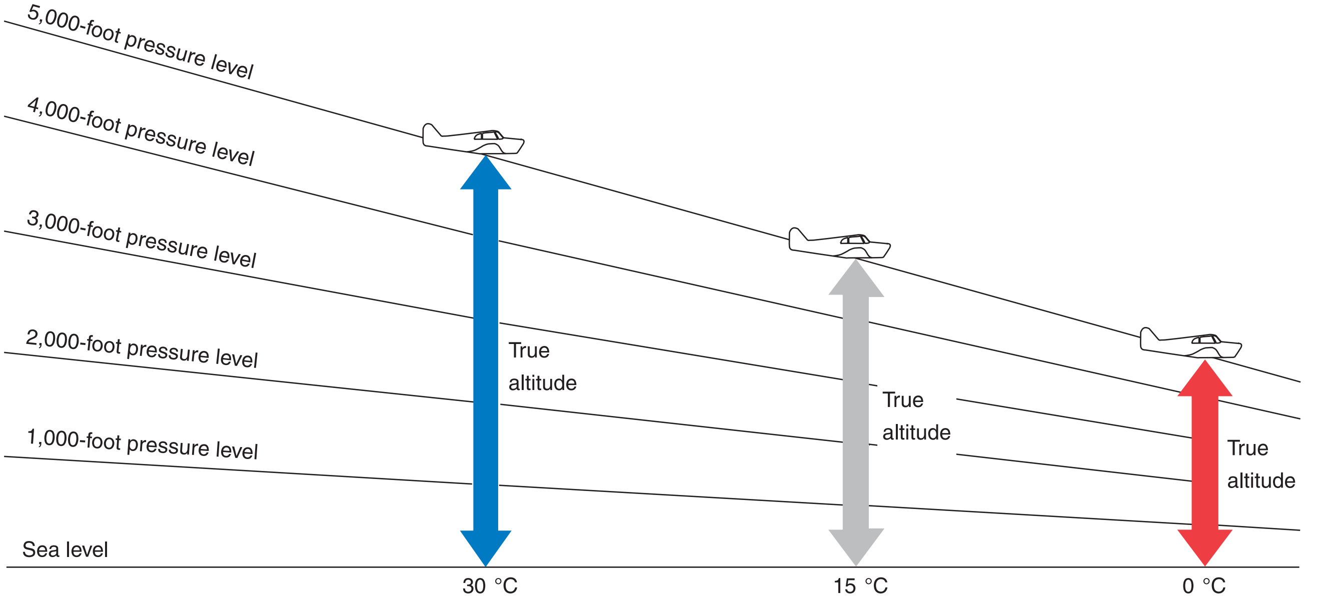


Figure 3-6. *Effects of nonstandard temperature on an altimeter.*

Kollsman window: A barometric scale window of a sensitive altimeter.

ICAO Cold Temperature Error Table

The cold temperature induced altimeter error may be significant when considering obstacle clearances when temperatures are well below standard. Pilots may wish to increase their minimum terrain clearance altitudes with a corresponding increase in ceiling from the normal minimum when flying in extreme cold temperature conditions. Higher altitudes may need to be selected when flying at low terrain clearances. Some flight management systems (FMS) with air data computers may implement a capability to compensate for cold temperature errors. Pilots flying with these systems should ensure they are aware of the conditions under which the system will automatically compensate. If compensation is applied by the FMS or manually, ATC must be informed that the aircraft is not flying the assigned altitude. Otherwise, vertical separation from other aircraft may be reduced creating a potentially hazardous situation. The following table, derived from ICAO standard formulas, shows how much error can exist when the temperature is extremely cold. To use the table, find the reported temperature in the left column, then read across the top row to the height above the airport/reporting station (e.g.: subtract the airport elevation from the altitude of the final approach fix). The intersection of the column and row is the amount of possible error.

Example: -10° Celsius and the FAF is 500 feet above the airport elevation. The reported current altimeter setting may place the aircraft as much as 50 feet below the altitude indicated by the altimeter.

Height above Airport in Feet

Reported Temp C°	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000	5000
+10	10	10	10	10	20	20	20	20	20	30	40	60	80	90
0	20	20	30	30	40	40	50	50	60	90	120	170	230	280
-10	20	30	40	50	60	70	80	90	100	150	200	290	390	490
-20	30	50	60	70	90	100	120	130	140	210	280	420	570	710
-30	40	60	80	100	120	130	150	170	190	280	380	570	760	950
-40	50	80	100	120	150	170	190	220	240	360	480	720	970	1210
-50	60	90	120	150	180	210	240	270	300	450	590	890	1190	1500

Figure 3-7. *Cold temperature corrections chart.*

Extreme differences between ambient and standard temperature must be taken into consideration to prevent controlled flight into terrain (CFIT). [Figure 3-7]

Any time the barometric pressure lapse rate differs from the standard of 1" Hg per thousand feet in the lower elevations, the indicated altitude will be different from the true altitude. For example, figure 3-8 shows an airplane at point A flying in air in which conditions are standard — the altimeter setting is 29.92" Hg. When the altimeter indicates 5,000 feet, the true altitude is also 5,000 feet.

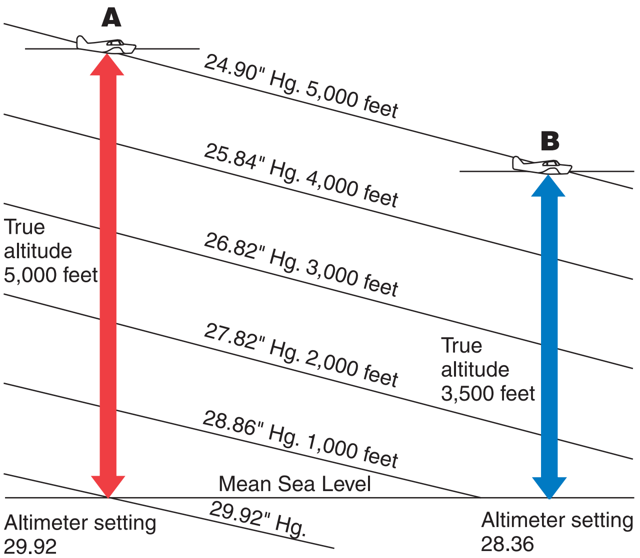


Figure 3-8. *Effects of nonstandard pressure on an altimeter.*

The airplane then flies to point B, where the pressure is lower than standard, and the altimeter setting is 28.36" Hg, but the pilot does not change the altimeter to this new altimeter setting. When the altimeter shows an indicated altitude of 5,000 feet, the true altitude, or the height above mean sea level, is only 3,500 feet.

The fact that the altitude indication is not always true lends itself to the memory aid, "When flying from hot to cold, or from a high to a low, look out below."

Encoding Altimeter

It is not sufficient in the airspace system for only the pilot to have an indication of the aircraft's altitude; the air traffic controller on the ground must also know the altitude of the aircraft. To provide this information, the aircraft may be equipped with an encoding altimeter.

When the ATC **transponder** is set to Mode C, the **encoding altimeter** supplies the transponder with a series of pulses identifying the flight level (in increments of 100 feet) at which the aircraft is flying. This series of pulses is transmitted to the ground radar where they appear on the controller's scope as an alphanumeric display around the return for the aircraft. The transponder allows the ground controller to identify the aircraft under his/her control and to know the pressure altitude at which each is flying.

A computer inside the encoding altimeter measures the pressure referenced from 29.92" Hg and delivers this data to the transponder. When the pilot adjusts the barometric scale to the local altimeter setting, the data sent to the transponder is not affected. 14 CFR part 91 requires the altitude transmitted by the transponder to be within 125 feet of the altitude indicated on the instrument used to maintain flight altitude.

Absolute Altimeter

The absolute altimeter, also called a radar or radio altimeter, measures the height of the aircraft above the terrain. It does this by transmitting a radio signal, either a frequency-modulated continuous-wave or a pulse to the ground, and accurately measuring the time used by the signal in traveling from the aircraft to the ground and returning. This transit time is modified with a time delay and is converted inside the indicator to distance in feet.

Most absolute altimeters have a provision for setting a decision height/decision altitude (DH/DA) or a minimum descent altitude (MDA) so that when the aircraft reaches this height above ground, a light will illuminate and/or an aural warning will sound. Absolute altimeters are incorporated into ground proximity warning systems (GPWS) and into some flight directors.

Memory Aid:
When flying from hot to cold, or from a high to a low, look out below!

Transponder: The airborne portion of the ATC radar beacon system.

Encoding altimeter: A sensitive altimeter that sends signals to the ATC transponder, showing the pressure altitude the aircraft is flying.

Airspeed Indicators

An airspeed indicator is a differential pressure gauge that measures the dynamic pressure of the air through which the aircraft is flying. Dynamic pressure is the difference in the ambient static air pressure and the total, or ram, pressure caused by the motion of the aircraft through the air. These two pressures are taken from the pitot-static system.

The mechanism of the airspeed indicator in figure 3-9 consists of a thin, corrugated phosphor-bronze aneroid, or diaphragm, that receives its pressure from the pitot tube. The instrument case is sealed and connected to the static ports. As the pitot pressure increases, or the static pressure decreases, the diaphragm expands, and this dimensional change is measured by a rocking shaft and a set of gears that drives a pointer across the instrument dial. Most airspeed indicators are calibrated in knots, or nautical miles per hour; some instruments show statute miles per hour, and some instruments show both.

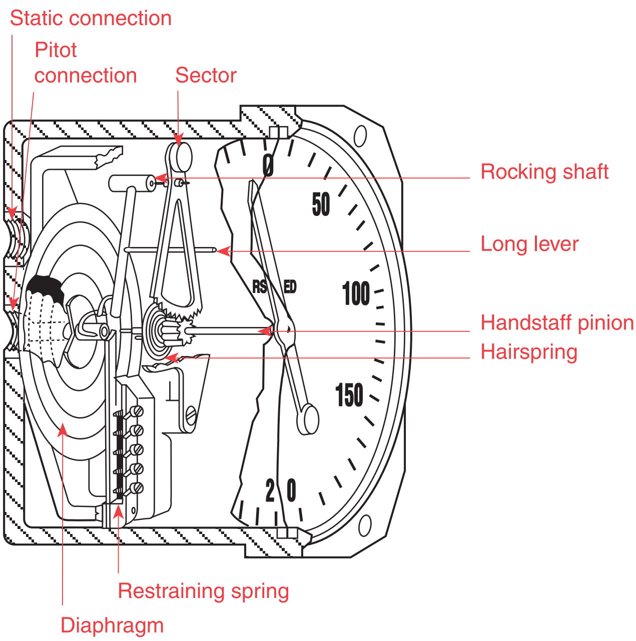


Figure 3-9. *Mechanism of an airspeed indicator.*

Types of Airspeed

Just as there are many types of altitude, there are many types of airspeed: indicated airspeed (IAS), calibrated airspeed (CAS), equivalent airspeed (EAS), and true airspeed (TAS).

Indicated Airspeed

Indicated airspeed is shown on the dial of the instrument, uncorrected for instrument or system errors.

Calibrated Airspeed

Calibrated airspeed is the speed the aircraft is moving through the air, which is found by correcting IAS for instrument and position errors. The POH/AFM has a chart or graph to correct IAS for these errors and provide the correct CAS for the various flap and landing gear configurations.

Equivalent Airspeed

Equivalent airspeed is CAS corrected for compression of the air inside the pitot tube. Equivalent airspeed is the same as CAS in standard atmosphere at sea level. As the airspeed and pressure altitude increase, the CAS becomes higher than it should be and a correction for compression must be subtracted from the CAS.

True Airspeed

True airspeed is CAS corrected for nonstandard pressure and temperature. True airspeed and CAS are the same in standard atmosphere at sea level. But under nonstandard conditions, TAS is found by applying a correction for pressure altitude and temperature to the CAS.

Some aircraft are equipped with true airspeed indicators that have a temperature-compensated aneroid bellows inside the instrument case. This bellows modifies the movement of the rocking shaft inside the instrument case so the pointer shows the actual TAS.

The true airspeed indicator provides both true and indicated airspeed. These instruments have the conventional airspeed mechanism, with an added subdial visible through cutouts in the regular dial. A knob on the instrument allows you to rotate the subdial and align an indication of the outside air temperature with the pressure altitude being flown. This alignment causes the instrument pointer to indicate the true airspeed on the subdial. [Figure 3-10]

Figure 3-10. *A true airspeed indicator allows the pilot to correct indicated airspeed for nonstandard temperature and pressure.*

Mach Number

As an aircraft approaches the speed of sound, the air flowing over certain areas of its surface speeds up until it reaches the speed of sound, and shock waves form. The indicated airspeed at which these conditions occur changes with temperature. Therefore airspeed, in this case, is not entirely adequate to warn the pilot of the impending problems. Mach number is more useful. Mach number is the ratio of the true airspeed of the aircraft to the speed of sound in the same atmospheric conditions. An aircraft flying at the speed of sound is flying at Mach 1.0.

Most high-speed aircraft are limited as to the maximum Mach number they can fly. This is shown on a Machmeter as a decimal fraction. [Figure 3-11] For example, if the Machmeter indicates .83 and the aircraft is flying at 30,000 feet where the speed of sound under standard conditions is 589.5 knots, the airspeed is 489.3 knots. The speed of sound varies with the air temperature, and if the aircraft were flying at Mach .83 at 10,000 feet where the air is much warmer, its airspeed would be 530 knots.

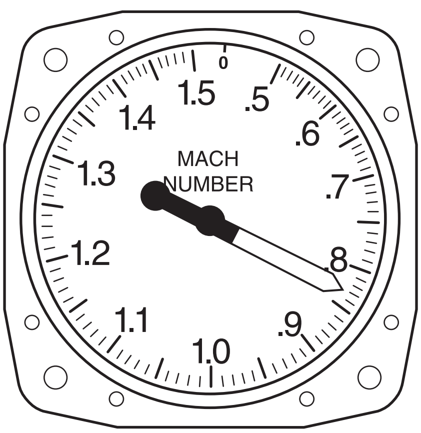


Figure 3-11. *A Machmeter shows the ratio of the speed of sound to the true airspeed the aircraft is flying.*

Maximum Allowable Airspeed

Some aircraft that fly at high subsonic speeds are equipped with maximum allowable airspeed indicators like the one in figure 3-12. This instrument looks much like a standard airspeed indicator, calibrated in knots, but has an additional pointer, colored red, checkered, or striped. The maximum airspeed pointer is actuated by an aneroid, or altimeter mechanism, that moves it to a lower value as air density decreases. By keeping the airspeed pointer at a lower value than the maximum pointer, the pilot avoids the onset of transonic shock waves.

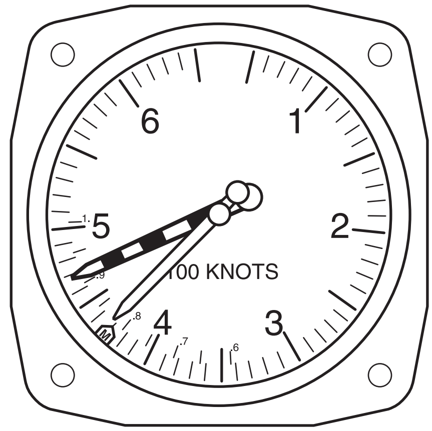


Figure 3-12. *A maximum allowable airspeed indicator has a movable pointer that indicates the never-exceed speed, which changes with altitude to avoid the onset of transonic shock waves.*

Airspeed Color Codes

The dial of an airspeed indicator is color coded to alert you, at a glance, of the significance of the speed at which the aircraft is flying. These colors and their associated airspeeds are shown in figure 3-13.

White arc	Flap operating range
Bottom	Flaps-down stall speed
Top	Maximum airspeed for flaps-down flight
Green arc	Normal operating range
Bottom	Flaps-up stall speed
Top	Maximum airspeed for rough air
Blue radial line	Airspeed for best single-engine rate-of-climb
Yellow arc	Structural warning area
Bottom	Maximum airspeed for rough air
Top	Never-exceed airspeed
Red radial line	Never-exceed airspeed

Figure 3-13. *Color codes for an airspeed indicator.*

Vertical Speed Indicators (VSI)

The vertical speed indicator (VSI) in figure 3-14 is also called a vertical velocity indicator (VVI) and was formerly known as a rate-of-climb indicator. It is a rate-of-pressure change instrument that gives an indication of any deviation from a constant pressure level.

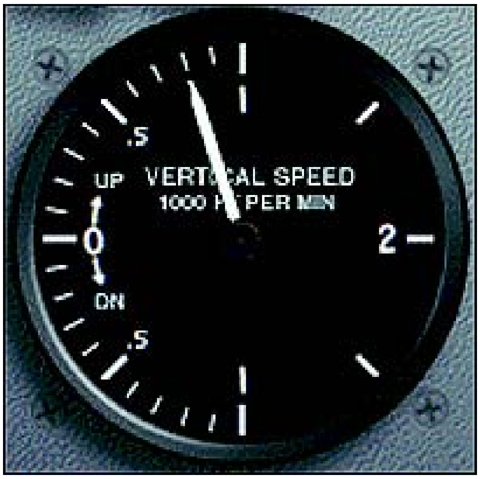


Figure 3-14. *Vertical speed indicator shows the rate of climb or descent in thousands of feet per minute.*

Inside the instrument case is an aneroid very much like the one in an airspeed indicator. Both the inside of this aneroid and the inside of the instrument case are vented to the static system, but the case is vented through a **calibrated orifice** that causes the pressure inside the case to change more slowly than the pressure inside the aneroid. As the aircraft ascends, the static pressure becomes lower and the pressure inside the case compresses the aneroid, moving the pointer upward, showing a climb and indicating the number of feet per minute the aircraft is ascending.

When the aircraft levels off, the pressure no longer changes, the pressure inside the case becomes the same as that inside the aneroid, and the pointer returns to its horizontal, or zero, position. When the aircraft descends, the static pressure increases and the aneroid expands, moving the pointer downward, indicating a descent.

The pointer indication in a VSI lags a few seconds behind the actual change in pressure, but it is more sensitive than an altimeter and is useful in alerting the pilot of an upward or downward trend, thereby helping maintain a constant altitude.

Some of the more complex VSIs, called instantaneous vertical speed indicators (IVSI), have two accelerometer-actuated air pumps that sense an upward or downward pitch of the aircraft and instantaneously create a pressure differential. By the time the pressure caused by the pitch acceleration dissipates, the altitude pressure change is effective.

Compass Systems

The Earth is a huge magnet, spinning in space, surrounded by a magnetic field made up of invisible **lines of flux**. These lines leave the surface at the magnetic north pole and reenter at the magnetic south pole.

Lines of magnetic flux have two important characteristics: any magnet that is free to rotate will align with them, and an electrical current is induced into any conductor that cuts across them. Most direction indicators installed in aircraft make use of one of these two characteristics.

Magnetic Compass

One of the oldest and simplest instruments for indicating direction is the magnetic compass. It is also one of the basic instruments required by 14 CFR part 91 for both VFR and IFR flight.

A magnet is a piece of material, usually a metal containing iron, that attracts and holds lines of magnetic flux. Every magnet regardless of size has two poles: a north pole and a south pole. When one magnet is placed in the field of another, the unlike poles attract each other and like poles repel.

An aircraft magnetic compass, such as the one in figure 3-15, has two small magnets attached to a metal float sealed inside a bowl of clear compass fluid similar to kerosene. A graduated scale, called a card, is wrapped around the float and viewed through a glass window with a **lubber line** across it. The card is marked with letters representing the cardinal directions, north, east, south, and west, and a number for each 30° between these letters. The final "0" is omitted from these directions; for example, 3 = 30°, 6 = 60°, and 33 = 330°. There are long and short graduation marks between the letters and numbers, with each long mark representing 10° and each short mark representing 5°.

Calibrated orifice: A hole of specific diameter used to delay the pressure change in the case of a vertical speed indicator.

Lines of flux: Invisible lines of magnetic force passing between the poles of a magnet.

Lubber line: The reference line used in a magnetic compass or heading indicator.

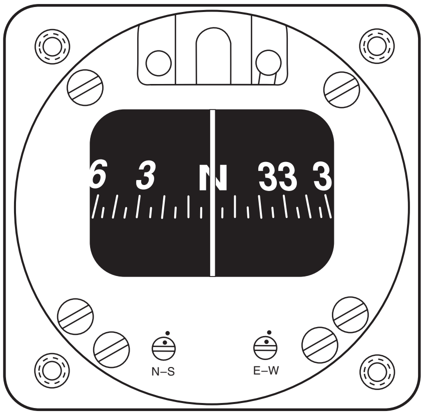


Figure 3-15. *A magnetic compass.*

The float and card assembly has a hardened steel pivot in its center that rides inside a special, spring-loaded, hard-glass jewel cup. The buoyancy of the float takes most of the weight off the pivot, and the fluid damps the oscillation of the float and card. This jewel-and-pivot type mounting allows the float freedom to rotate and tilt up to approximately 18° angle of bank. At steeper bank angles, the compass indications are erratic and unpredictable.

The compass housing is entirely full of compass fluid. To prevent damage or leakage when the fluid expands and contracts with temperature changes, the rear of the compass case is sealed with a flexible diaphragm, or in some compasses, with a metal bellows.

The magnets align with the Earth's magnetic field and the pilot reads the direction on the scale opposite the lubber line. In figure 3-15, the pilot sees the compass card from its back side. When you are flying north as the compass shows, east is to your right, but on the card "33" which represents 330° (west of north) is to the right of north. The reason for this apparent backward graduation is that the card remains stationary, and the compass housing and the pilot turn around it, always viewing the card from its back side.

A compensator assembly mounted on the top or bottom of the compass allows an aviation maintenance technician (AMT) to create a magnetic field inside the compass housing that cancels the influence of local outside magnetic fields. This is done to correct for deviation error. The compensator assembly has two shafts whose ends have screwdriver slots accessible from the front of the compass. Each shaft rotates one or two small compensating magnets. The end of one shaft is marked E-W, and its magnets affect the compass when the aircraft is pointed east or west. The other shaft is marked N-S and its magnets affect the compass when the aircraft is pointed north or south.

Compass Errors

The magnetic compass is the simplest instrument in the panel, but it is subject to a number of errors that must be considered.

Variation

The Earth rotates about its geographic axis, and maps and charts are drawn using meridians of longitude that pass through the geographic poles. Directions measured from the geographic poles are called true directions. The north magnetic pole to which the magnetic compass points is not colocated with the geographic north pole but is some 1,300 miles away, and directions measured from the magnetic poles are called magnetic directions. In aerial navigation, the difference between true and magnetic directions is called **variation**. This same angular difference in surveying and land navigation is called declination.

Figure 3-16 shows the **isogonic lines** that identify the number of degrees of variation in their area. The line that passes near Chicago is called the **agonic line**, and anywhere along this line the two poles are aligned, and there is no variation. East of this line, the magnetic pole is to the west of the geographic pole and a correction must be applied to a compass indication to get a true direction.

When you fly in the Washington, DC area, for example, the variation is 10° west, and if you want to fly a true course of south (180°), the variation must be added to this and the magnetic course to fly is 190°. When you fly in the Los Angeles, CA area, the variation is about 15° east. To fly a true course of 180° there, you would have to subtract the variation and fly a magnetic course of 165°. The variation error does not change with the heading of the aircraft; it is the same anywhere along the isogonic line.

Variation: The compass error caused by the difference in the physical locations of the magnetic north pole and the geographic north pole.

Isogonic lines: Lines drawn across aeronautical charts connecting points having the same magnetic variation.

Agonic line: An irregular imaginary line across the surface of the Earth along which the magnetic and geographic poles are in alignment and along which there is no magnetic variation.

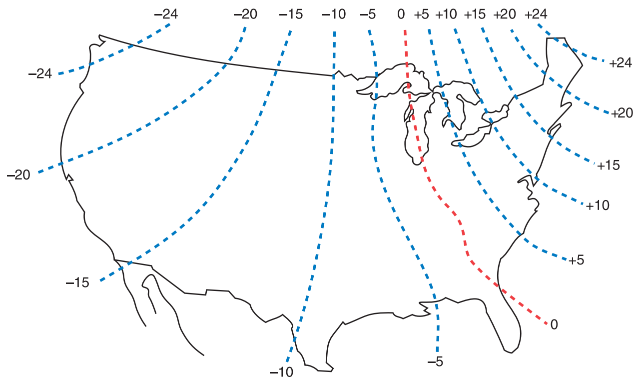


Figure 3-16. *Isogonic lines are lines of equal variation.*

Deviation

The magnets in a compass align with any magnetic field. Local magnetic fields in an aircraft caused by electrical current flowing in the structure, in nearby wiring or any magnetized part of the structure, will conflict with the Earth's magnetic field and cause a compass error called **deviation**.

Deviation, unlike variation, is different on each heading, but it is not affected by the geographic location. Variation error cannot be reduced nor changed, but deviation error can be minimized when an AMT performs the maintenance task, "swinging the compass."

Most airports have a compass rose, which is a series of lines marked out on a taxiway or ramp at some location where there is no magnetic interference. Lines, oriented to magnetic north, are painted every 30° as shown in figure 3-17.

The AMT aligns the aircraft on each magnetic heading and adjusts the compensating magnets to minimize the difference between the compass indication and the actual magnetic heading of the aircraft. Any error that cannot be removed is recorded on a compass correction card, like the one in figure 3-18, and placed in a card holder near the compass. If you want to fly a magnetic heading of 120°, and the aircraft is operating with the radios on, you would have to fly a compass heading of 123°.

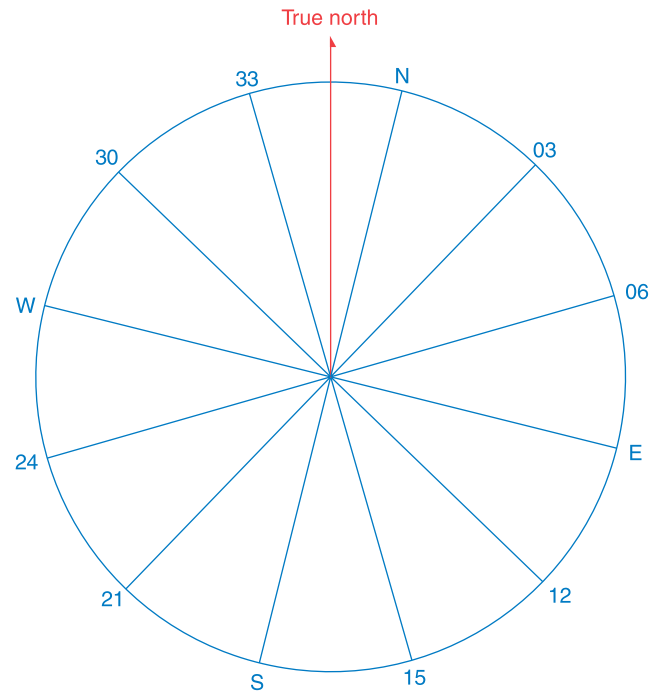


Figure 3-17. *A compass rose upon which deviation error is compensated for.*

FOR	000	030	060	090	120	150
STEER						
RDO. ON	001	032	062	095	123	155
RDO. OFF	002	031	064	094	125	157

FOR	180	210	240	270	300	330
STEER						
RDO. ON	176	210	243	271	296	325
RDO. OFF	174	210	240	273	298	327

Figure 3-18. *A compass correction card shows the deviation correction for any heading.*

The corrections for variation and deviation must be applied in the correct sequence. To find the **compass course** when the true course is known:

True Course ± Variation = Magnetic Course ± Deviation = Compass Course

Deviation: A magnetic compass error caused by local magnetic fields within the aircraft. Deviation error is different on each heading.

Compass course: A true course corrected for variation and deviation errors.

Mnemonic aid for calculating magnetic course:
East is least (subtract variation from true course), west is best (add variation to true course).

To find the true course that is being flown when the compass course is known:

Compass Course ± Deviation = Magnetic Course ± Variation = True Course

Dip Errors

The lines of magnetic flux are considered to leave the Earth at the magnetic north pole and enter at the magnetic south pole. At both locations the lines are perpendicular to the Earth's surface. At the magnetic equator, which is halfway between the poles, the lines are parallel with the surface. The magnets in the compass align with this field, and near the poles they dip, or tilt, the float and card. The float is balanced with a small dip-compensating weight, so it stays relatively level when operating in the middle latitudes of the northern hemisphere. This dip along with this weight causes two very noticeable errors: northerly turning error and acceleration error.

The pull of the vertical component of the Earth's magnetic field causes northerly turning error, which is apparent on a heading of north or south. When an aircraft, flying on a heading of north, makes a turn toward east, the aircraft banks to the right, and the compass card tilts to the right. The vertical component of the Earth's magnetic field pulls the north-seeking end of the magnet to the right, and the float rotates, causing the card to rotate toward west, the direction opposite the direction the turn is being made. [Figure 3-19]

If the turn is made from north to west, the aircraft banks to the left and the card tilts to the left. The magnetic field pulls on the end of the magnet that causes the card to rotate toward east. This indication is again opposite to the direction the turn is being made. The rule for this error is: when starting a turn from a northerly heading, the compass indication lags behind the turn.

When an aircraft is flying on a heading of south and begins a turn toward east, the Earth's magnetic field pulls on the end of the magnet that rotates the card toward east, the same direction the turn is being made. If the turn is made from south toward west, the magnetic pull will start the card rotating toward west—again, in the same direction the turn is being made. The rule for this error is: When starting a turn from a southerly heading, the compass indication leads the turn.

In acceleration error, the dip-correction weight causes the end of the float and card marked N (this is the south-seeking end) to be heavier than the opposite end. When the aircraft is flying at a constant speed on a heading of either east or west, the float and card are level. The effects of magnetic dip and the weight are approximately equal. If the aircraft accelerates on a heading of east (as in figure 3-20), the inertia of the weight holds its end of the float back, and the card rotates toward north. As soon as the speed of the aircraft stabilizes, the card swings back to its east indication.

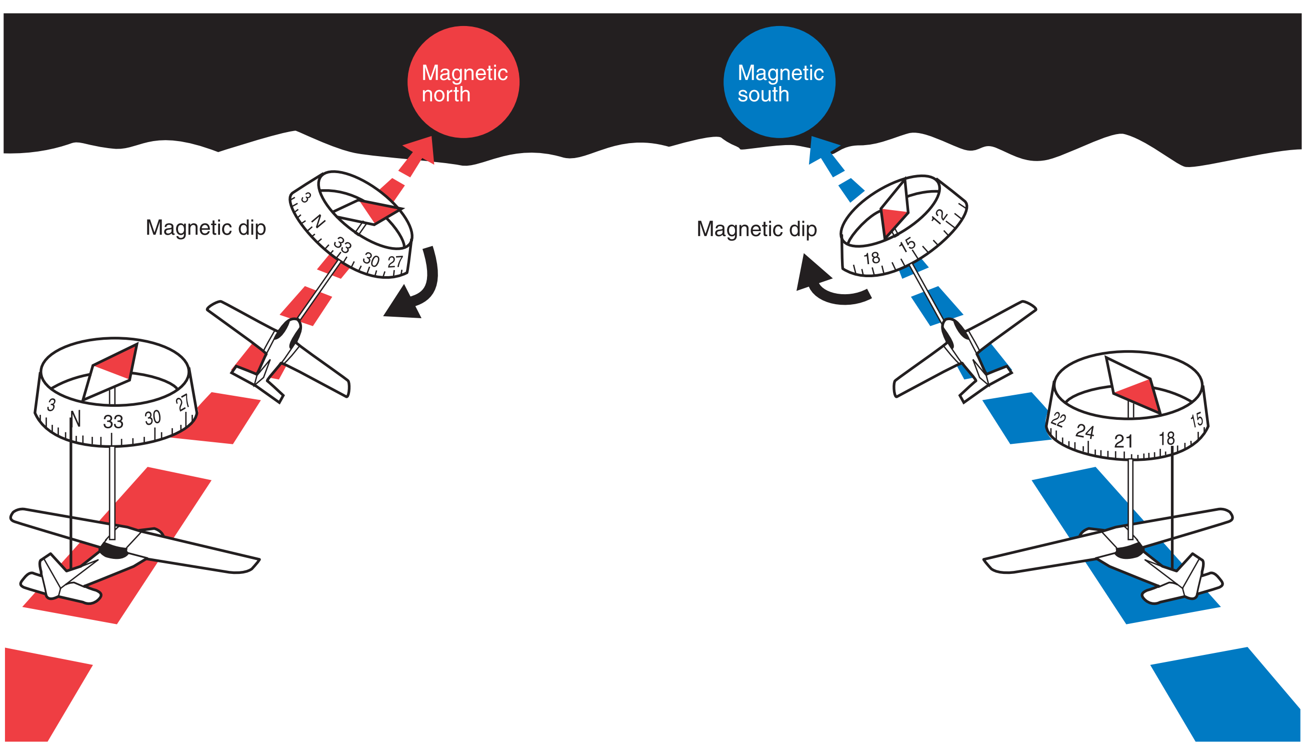


Figure 3-19. *Northerly turning error.*

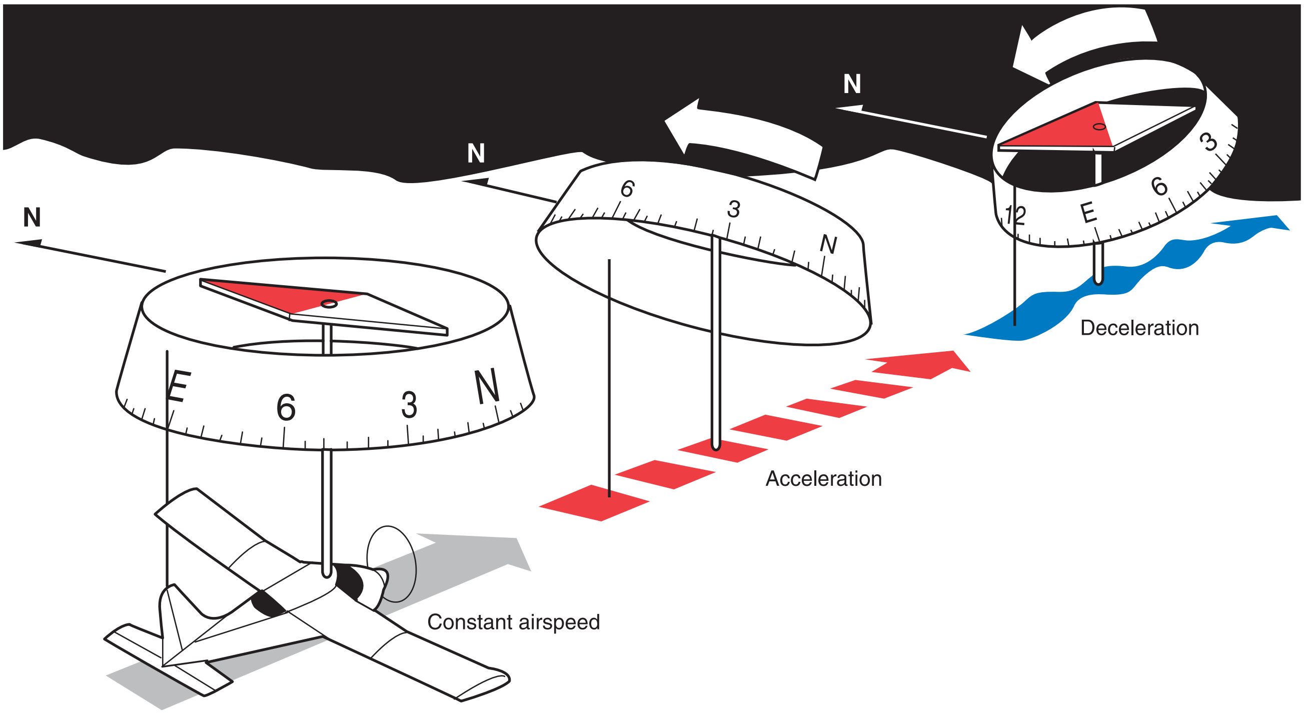


Figure 3-20. *The effects of acceleration error.*

If, while flying on this easterly heading, the aircraft decelerates, the inertia causes the weight to move ahead and the card rotates toward south until the speed again stabilizes.

When flying on a heading of west, the same things happen. Inertia from acceleration causes the weight to lag, and the card rotates toward north. When the aircraft decelerates on a heading of west, inertia causes the weight to move ahead and the card rotates toward south.

Oscillation Error

Oscillation is a combination of all of the other errors, and it results in the compass card swinging back and forth around the heading being flown. When setting the gyroscopic heading indicator to agree with the magnetic compass, use the average indication between the swings.

Vertical Card Magnetic Compasses

The floating-magnet type of compass not only has all the errors just described, but lends itself to confused reading. It is easy to begin a turn in the wrong direction because its card appears backward. East is on the west side. The vertical card magnetic compass eliminates some of the errors and confusion. The dial of this compass is graduated with letters representing the cardinal directions, numbers every 30°, and marks every 5°. The dial is rotated by a set of gears from the shaft-mounted magnet, and the nose of the symbolic airplane on the instrument glass represents the lubber line for reading the heading of the aircraft from the dial. Oscillation of the magnet is damped by **eddy currents** induced into an aluminum damping cup. [Figure 3-21]

Lags or Leads

When starting a turn from a northerly heading, the compass lags behind the turn. When starting a turn from a southerly heading, the compass leads the turn.

ANDS

A memory jogger for the effect of acceleration error is the word “ANDS”: Acceleration causes an indication toward North, Deceleration causes an indication toward South.

Eddy currents: Current induced in a metal cup or disc when it is crossed by lines of flux from a moving magnet.

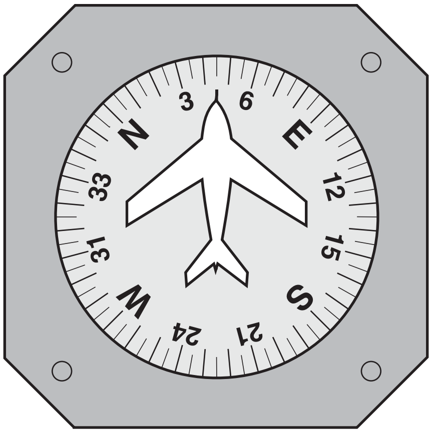


Figure 3-21. *A vertical card magnetic compass.*

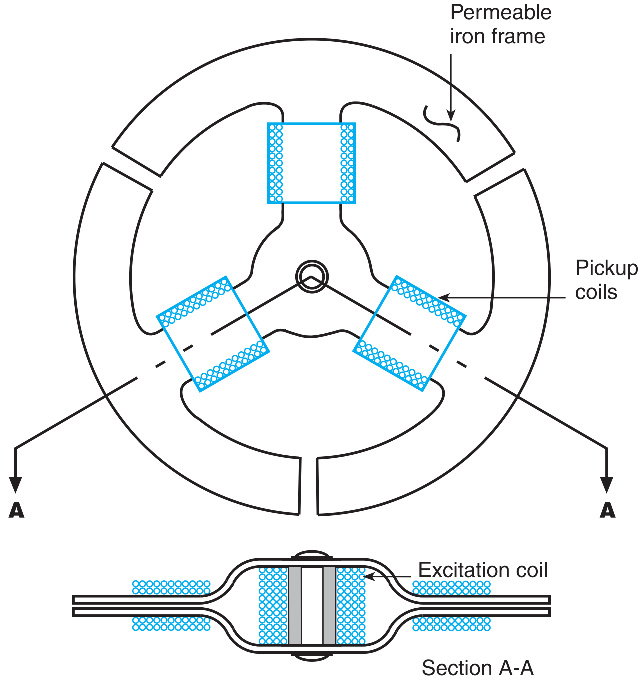


Figure 3-22. *The soft iron frame of the flux valve accepts the flux from the Earth's magnetic field each time the current in the center coil reverses. This flux causes current to flow in the three pickup coils.*

Flux Gate Compass

As mentioned earlier, the lines of flux in the Earth's magnetic field have two basic characteristics: a magnet will align with these lines, and an electrical current is induced, or generated, in any wire crossed by them.

The flux gate compass that drives slaved gyros uses the characteristic of **current induction**. The flux valve is a small segmented ring, like the one in figure 3-22, made of soft iron that readily accepts lines of magnetic flux. An electrical coil is wound around each of the three legs to accept the current induced in this ring by the Earth's magnetic field. A coil wound around the iron spacer in the center of the frame has 400-Hz alternating current (a.c.) flowing through it. During the times when this current reaches its peak, twice during each cycle, there is so much magnetism produced by this coil that the frame cannot accept the lines of flux from the Earth's field.

But as the current reverses between the peaks, it demagnetizes the frame so it can accept the flux from the Earth's field. As this flux cuts across the windings in the three coils, it causes current to flow in them. These three coils are connected in such a way that the current flowing in them changes as the heading of the aircraft changes. [Figure 3-23]

The three coils are connected to three similar but smaller coils in a **synchro** inside the instrument case. The synchro rotates the dial of a radio magnetic indicator (RMI) or a horizontal situation indicator (HSI).

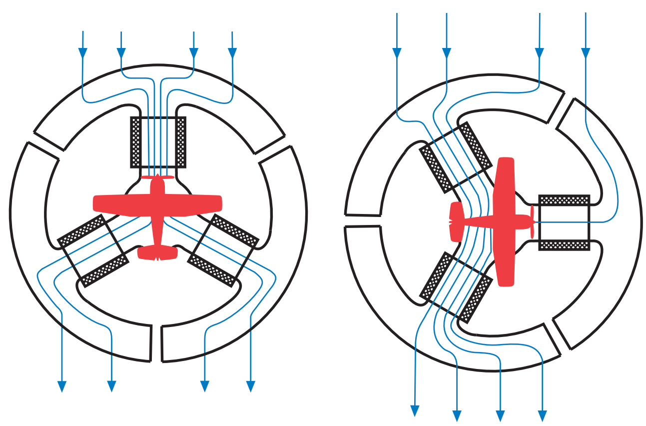


Figure 3-23. *The current in each of the three pickup coils changes with the heading of the aircraft.*

Current induction: An electrical current is induced into, or generated in, any conductor that is crossed by lines of flux from any magnet.

Synchro: A device used to transmit indications of angular movement or position from one location to another.

Remote Indicating Compass

Remote indicating compasses were developed to compensate for the errors and limitations of the older type of heading indicators. The two panel-mounted components of a typical system are the pictorial navigation indicator, and the slaving control and compensator unit. [Figure 3-24] The pictorial navigation indicator is commonly referred to as a horizontal situation indicator.

Figure 3-24. *Pictorial navigation indicator; slaving control and compensator unit.*

The slaving control and compensator unit has a pushbutton that provides a means of selecting either the "slaved gyro" or "free gyro" mode. This unit also has a slaving meter and two manual heading-drive buttons. The slaving meter indicates the difference between the displayed heading and the magnetic heading. A right deflection indicates a clockwise error of the compass card; a left deflection indicates a counterclockwise error. Whenever the aircraft is in a turn and the card rotates, the slaving meter will show a full deflection to one side or the other. When the system is in "free gyro" mode, the compass card may be adjusted by depressing the appropriate heading-drive button.

A separate unit, the magnetic slaving transmitter is mounted remotely; usually in a wingtip to eliminate the possibility of magnetic interference. It contains the flux valve, which is the direction-sensing device of the system. A concentration of lines of magnetic force, after being amplified, becomes a signal relayed to the heading indicator unit which is also remotely mounted. This signal operates a torque motor in the heading indicator unit which precesses the gyro unit until it is aligned with the transmitter signal. The magnetic slaving transmitter is connected electrically to the HSI.

There are a number of designs of the remote indicating compass; therefore, only the basic features of the system are covered here. As an instrument pilot, you should become familiar with the characteristics of the equipment in your aircraft.

As instrument panels become more crowded and the pilot's available scan time is reduced by a heavier cockpit workload, instrument manufacturers have worked towards combining instruments. One good example of this is the RMI in figure 3-25. The compass card is driven by signals from the flux valve, and the two pointers are driven by an **automatic direction finder (ADF)** and a **very-high-frequency omnidirectional range (VOR)**.

Figure 3-25. *The compass card in this RMI is driven by signals from a flux valve and it indicates the heading of the aircraft opposite the upper center index mark.*

Automatic direction finder (ADF): Electronic navigation equipment that operates in the low- and medium-frequency bands.

Very-high-frequency omnidirectional range (VOR): Electronic navigation equipment in which the cockpit instrument identifies the radial or line from the VOR station measured in degrees clockwise from magnetic north, along which the aircraft is located.

Gyroscopic Systems

Flight without reference to a visible horizon can be safely accomplished by the use of gyroscopic instrument systems and the two characteristics of gyroscopes which are: **rigidity** and **precession**. These systems include: attitude, heading, and rate instruments, along with their power sources. These instruments include a gyroscope (or gyro) which is a small wheel with its weight concentrated around its periphery. When this wheel is spun at high speed, it becomes rigid and resists any attempt to tilt it or turn it in any direction other than around its spin axis.

Attitude and heading instruments operate on the principal of rigidity. For these instruments the gyro remains rigid in its case and the aircraft rotates about it.

Rate indicators, such as turn indicators and turn coordinators, operate on the principal of precession. In this case the gyro precesses (or rolls over) proportionate to the rate the aircraft rotates about one or more of its axes.

Power Sources

Aircraft and instrument manufacturers have designed redundancy into the flight instruments so that any single failure will not deprive the pilot of his/her ability to safely conclude the flight.

Gyroscopic instruments are crucial for instrument flight; therefore, they are powered by separate electrical or pneumatic sources.

Electrical Systems

Many general aviation aircraft that use pneumatic attitude indicators use electric rate indicators and vice versa. Some instruments identify their power source on their dial, but it is extremely important that pilots consult the POH/AFM to determine the power source of all instruments to know what action to take in the event of an instrument failure.

Direct current (d.c.) electrical instruments are available in 14- or 28-volt models, depending upon the electrical system in the aircraft. Alternating current (a.c.) is used to operate some attitude gyros and autopilots. Aircraft that have only d.c. electrical systems can use a.c. instruments by installing a solid-state d.c. to a.c. **inverter**, which changes 14 or 28 volts d.c. into three-phase 115-volt, 400-Hz a.c.

Pneumatic Systems

Pneumatic gyros are driven by a jet of air impinging on buckets cut into the periphery of the wheel. This stream of air is obtained on many aircraft by evacuating the instrument case and allowing filtered air to flow into the case through a nozzle to spin the wheel.

Venturi Tube Systems

Aircraft that do not have a pneumatic pump to evacuate the instrument cases can use **venturi tubes** mounted on the outside of the aircraft, similar to the system shown in figure 3-26. Air flowing through these tubes speeds up in the narrowest part, and according to Bernoulli's principle, the pressure drops. This location is connected to the instrument case by a piece of tubing. The two attitude instruments operate on approximately 4" Hg suction; the turn-and-slip indicator needs only 2" Hg, so a pressure-reducing needle valve is used to decrease the suction. Filtered air flows into the instruments through filters built into the instrument cases. In this system, ice can clog the venturi tube and stop the instruments when they are most needed.

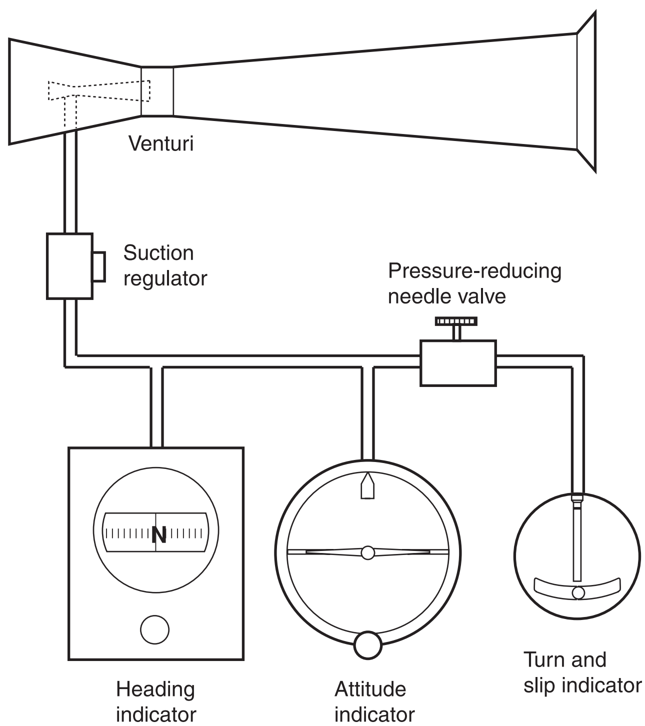


Figure 3-26. *A venturi tube provides the low pressure inside the instrument case to drive the gyros.*

Rigidity: The characteristic of a gyroscope that prevents its axis of rotation tilting as the Earth rotates.

Precession: The characteristic of a gyroscope that causes an applied force to be felt, not at the point of application, but 90° from that point in the direction of rotation.

Inverter: A solid-state electronic device that converts electrical current from d.c. into a.c. to operate a.c. gyro instruments.

Venturi tube: A specially-shaped tube attached to the outside of an aircraft to produce suction to operate gyro instruments.

Wet-Type Vacuum Pump Systems

Steel-vane air pumps have been used for many years to evacuate the instrument cases. The discharge air is used to inflate rubber deicer boots on the wing and empennage leading edges. The vanes in these pumps are lubricated by a small amount of engine oil metered into the pump and this oil is discharged with the air. To keep the oil from deteriorating the rubber boots, it must be removed with an oil separator like the one in figure 3-27.

The vacuum pump moves a greater volume of air than is needed to supply the instruments with the suction needed, so a **suction-relief valve** is installed in the inlet side of the pump. This spring-loaded valve draws in just enough air to maintain the required low pressure inside the instruments, as is shown on the suction gauge in the instrument panel. Filtered air enters the instrument cases from a central air filter. As long as aircraft fly at relatively low altitudes, enough air is drawn into the instrument cases to spin the gyros at a sufficiently high speed.

Dry-Air Pump Systems

As flight altitudes increase, the air is less dense and more air must be forced through the instruments. Air pumps that do not mix oil with the discharge air are used in high-flying aircraft.

Steel vanes sliding in a steel housing need to be lubricated, but vanes made of a special formulation of carbon sliding inside a carbon housing provide their own lubrication as they wear in a microscopic amount.

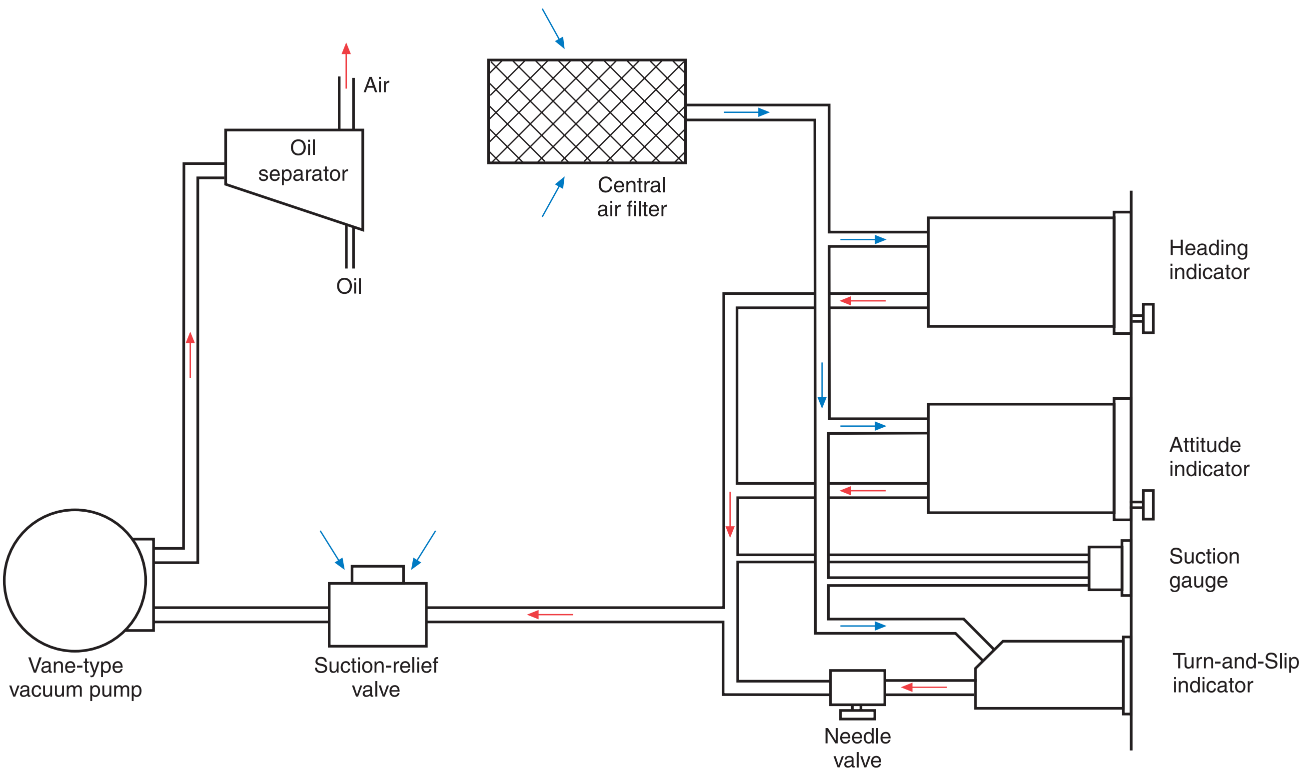


Figure 3-27. *Single-engine instrument vacuum system using a steel-vane wet-type vacuum pump.*

Suction-relief valve: A relief valve in an instrument vacuum system to maintain the correct low pressure inside the instrument case for the proper operation of the gyros.

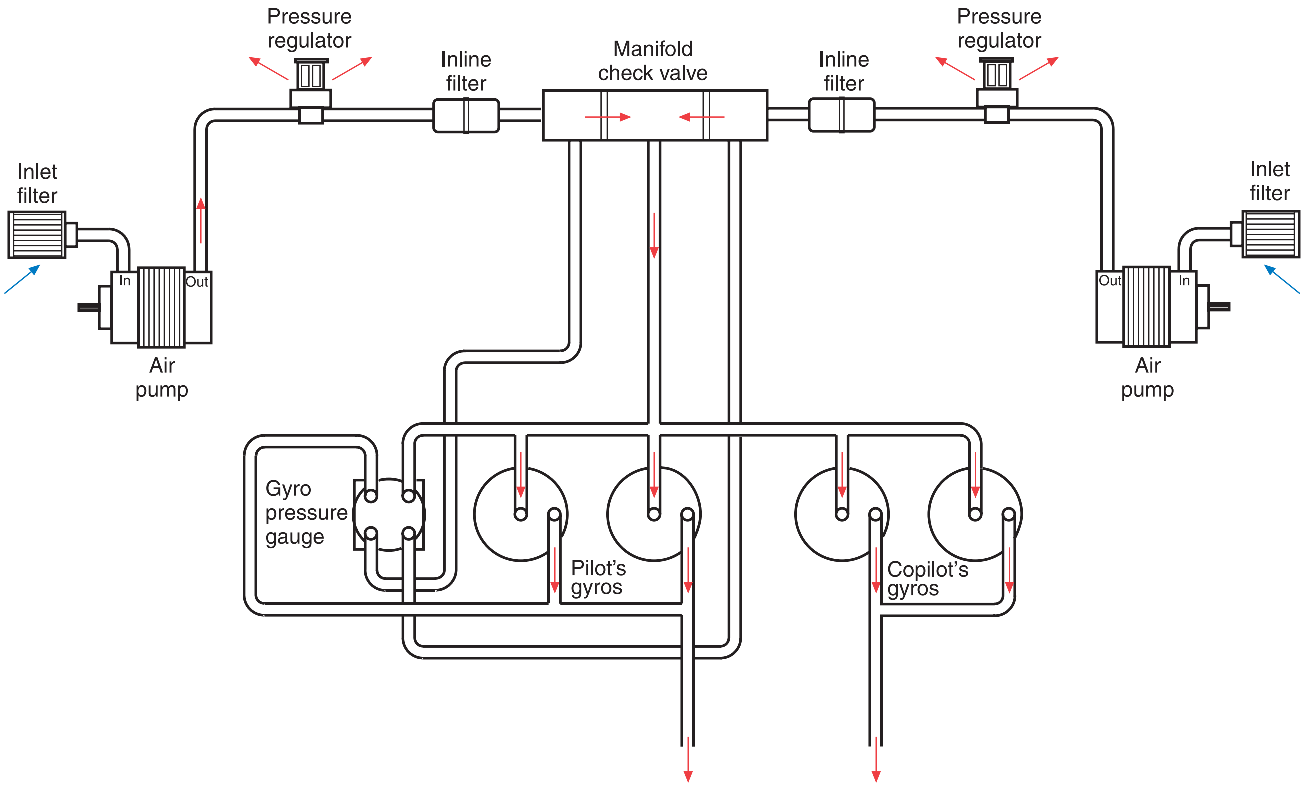


Figure 3-28. *Twin-engine instrument pressure system using a carbon-vane dry-type air pump.*

Pressure Systems

Figure 3-28 is a diagram of the instrument pneumatic system of a twin-engine general aviation airplane. Two dry air pumps are used with filters in their inlet to filter out any contaminants that could damage the fragile carbon vanes in the pump. 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. 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. If either engine should become inoperative, or if either pump should fail, the check valve will isolate the inoperative system and the instruments will be driven by air from the operating system. After the air passes through the instruments and drives the gyros, it is exhausted from the case. The gyro pressure gauge measures the pressure drop across the instruments.

Gyroscopic Instruments

Attitude Indicators

The first attitude instrument (AI) was originally referred to as an artificial horizon, later as a gyro horizon; now it is more properly called an attitude indicator. Its operating mechanism is a small brass wheel with a vertical spin axis, spun at a high speed by either a stream of air impinging on buckets cut into its periphery, or by an electric motor. The gyro is mounted in a **double gimbal**, which allows the aircraft to pitch and roll about the gyro as it remains fixed in space.

A horizon disk is attached to the gimbals so it remains in the same plane as the gyro, and the aircraft pitches and rolls about it. On the early instruments, this was just a bar that represented the horizon, but now it is a disc with a line representing the horizon and both pitch marks and bank-angle lines. The top half of the instrument dial and horizon disc is blue, representing the sky; and the bottom half is brown, representing

Double gimbal: A type of mount used for the gyro in an attitude instrument. The axes of the two gimbals are at right angles to the spin axis of the gyro allowing free motion in two planes around the gyro.

the ground. A bank index at the top of the instrument shows the angle of bank marked on the banking scale with lines that represent 10°, 20°, 30°, 60°, and 90°. [Figure 3-29]

Figure 3-29. *The dial of this attitude indicator has reference lines to show pitch and roll.*

A small symbolic aircraft is mounted in the instrument case so it appears to be flying relative to the horizon. A knob at the bottom center of the instrument case raises or lowers the aircraft to compensate for pitch trim changes as the airspeed changes. The width of the wings of the symbolic aircraft and the dot in the center of the wings represent a pitch change of approximately 2°.

For an AI to function properly, the gyro must remain vertically upright while the aircraft rolls and pitches around it. The bearings in these instruments have a minimum of friction; however, even this small amount places a restraint on the gyro which produces a precessive force causing the gyro to tilt. To minimize this tilting, an erection mechanism inside the instrument case applies a force any time the gyro tilts from its vertical position. This force acts in such a way to return the spinning wheel to its upright position.

The older artificial horizons were limited in the amount of pitch or roll they could tolerate, normally about 60° in pitch and 100° in roll. After either of these limits was exceeded, the gyro housing contacted the gimbal, applying such a precessive force that the gyro tumbled. Because of this limitation, these instruments had a caging mechanism that locked the gyro in its vertical position during any maneuvers that exceeded the instrument limits. Newer instruments do not have these restrictive tumble limits; therefore, they do not have a caging mechanism.

When an aircraft engine is first started and pneumatic or electric power is supplied to the instruments, the gyro is not erect. A self-erecting mechanism inside the instrument actuated by the force of gravity applies a precessive force, causing the gyro to rise to its vertical position. This erection can take as long as 5 minutes, but is normally done within 2 to 3 minutes.

Attitude indicators are free from most errors, but depending upon the speed with which the erection system functions, there may be a slight nose-up indication during a rapid acceleration and a nose-down indication during a rapid deceleration. There is also a possibility of a small bank angle and pitch error after a 180° turn. These inherent errors are small and correct themselves within a minute or so after returning to straight-and-level flight.

Heading Indicators

A magnetic compass is a dependable instrument and is used as a backup instrument. But it has so many inherent errors that it has been supplemented with gyroscopic heading indicators.

The gyro in an attitude indicator is mounted in a double gimbal in such a way that its spin axis is *vertical*. It senses pitch and roll, but cannot sense rotation about its vertical, or spin, axis. The gyro in a heading indicator is also mounted in a double gimbal, but its spin axis is *horizontal*, and it senses rotation about the vertical axis of the aircraft.

Gyro heading indicators, with the exception of slaved gyro indicators, are not north-seeking, and they must be set to the appropriate heading by referring to a magnetic compass. Rigidity causes them to maintain this heading indication, without the oscillation and other errors inherent in a magnetic compass.

Older directional gyros use a drum-like card marked in the same way as the magnetic compass card. The gyro and the card remain rigid inside the case, and you view the card from the back. This allows the possibility you might start a turn in the wrong direction. A knob on the front of the instrument, below the dial, can be pushed in to engage the gimbals. This locks the gimbals and allows you to rotate the gyro and card until the number opposite the lubber line is the same as that of the magnetic compass. When the knob is pulled out, the gyro remains rigid and the aircraft is free to turn around the card.

Directional gyros are almost all air-driven by evacuating the case and allowing filtered air to flow into the case and out through a nozzle, blowing against buckets cut in the periphery of the wheel. Bearing friction causes the gyro to precess and the indication to drift. When using these instruments, it is standard practice to reset them to agree with the magnetic compass about every 15 minutes.

Heading indicators like the one in figure 3-30 work on the same principle as the older horizontal card indicators, except that the gyro drives a vertical dial that looks much like the dial of a vertical card magnetic compass. The heading of the aircraft is shown against the nose of the symbolic aircraft on the instrument glass, which serves as the lubber line. A knob in the front of the instrument may be pushed in and turned to rotate the gyro and dial. The knob is spring-loaded so it will disengage from the gimbals as soon as it is released. This instrument should be checked about every 15 minutes to see if it agrees with the magnetic compass.

Figure 3-30. *The heading indicator is not north-seeking, but must be set to agree with the magnetic compass.*

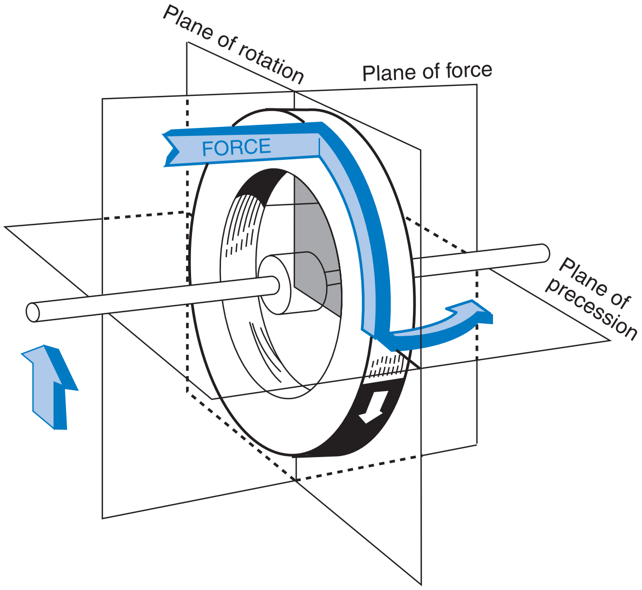


Figure 3-31. *Precession causes a force applied to a spinning wheel to be felt 90° from the point of application in the direction of rotation.*

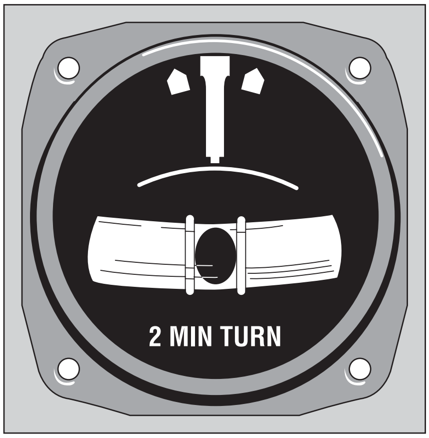


Figure 3-32. *The turn-and-slip indicator.*

Turn Indicators

Attitude and heading indicators function on the principle of rigidity, but rate instruments such as the turn-and-slip indicator operate on precession. Precession is the characteristic of a gyroscope that causes an applied force to produce a movement, not at the point of application, but at a point 90° from the point of application in the direction of rotation. [Figure 3-31]

Turn-and-Slip Indicator

The first gyroscopic aircraft instrument was the turn indicator in the needle and ball, or turn-and-bank indicator, which has more recently been called a turn-and-slip indicator. [Figure 3-32]

The inclinometer in the instrument is a black glass ball sealed inside a curved glass tube that is partially filled with a liquid, much like compass fluid. This ball measures the relative strength of the force of gravity and the force of inertia caused by a turn. When the aircraft is flying straight-and-level, there is no inertia acting on the ball, and it remains in the center of the tube between two wires. In a turn made with a bank angle that is too steep, the force of gravity is greater than the inertia and the ball rolls down to the inside of the turn. If the turn is made with too shallow a bank angle, the inertia is greater than gravity and the ball rolls upward to the outside of the turn.

The inclinometer does not indicate the amount of bank, neither is it limited to an indication of slip; it only indicates the relationship between the angle of bank and the rate of yaw.

The turn indicator is a small gyro spun either by air or by an electric motor. The gyro is mounted in a single gimbal with its spin axis parallel to the lateral axis of the aircraft and the axis of the gimbal parallel with the longitudinal axis. [Figure 3-33]

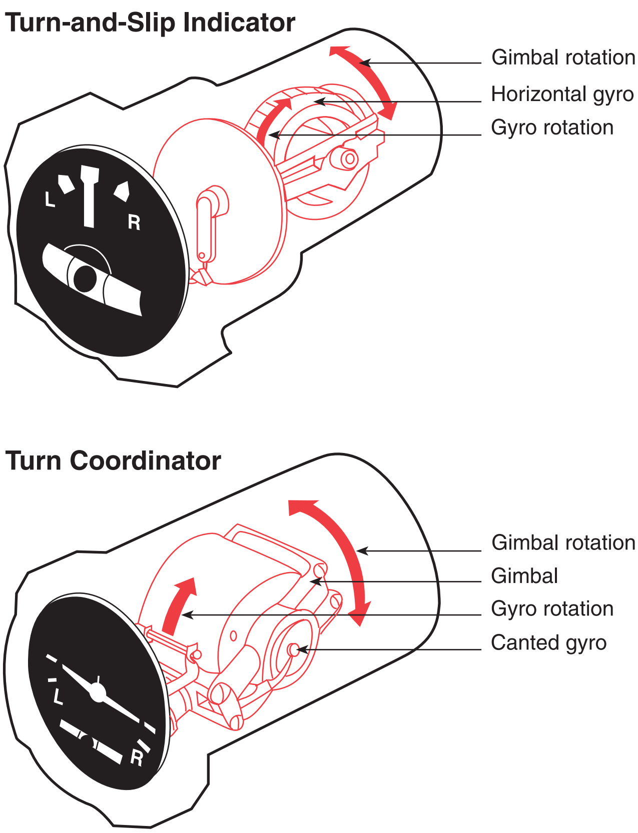


Figure 3-33. *The rate gyro in a turn-and-slip indicator and turn coordinator.*

When the aircraft yaws, or rotates about its vertical axis, it produces a force in the horizontal plane that, due to precession, causes the gyro and its gimbal to rotate about the gimbal axis. It is restrained in this rotation plane by a calibration spring; it rolls over just enough to cause the pointer to deflect until it aligns with one of the **doghouse**-shaped marks on the dial, when the aircraft is making a standard-rate turn.

The dial of these instruments is marked "2 MIN TURN." Some turn-and-slip indicators used in faster aircraft are marked "4 MIN TURN." In either instrument, a standard-rate turn is being made whenever the needle aligns with a doghouse.

Turn Coordinator

The major limitation of the older turn-and-slip indicator is that it senses rotation only about the vertical axis of the aircraft. It tells nothing of the rotation around the longitudinal axis, which in normal flight occurs before the aircraft begins to turn.

A turn coordinator operates on precession, the same as the turn indicator, but its gimbal frame is angled upward about 30° from the longitudinal axis of the aircraft. This allows it to sense both roll and yaw. Some turn coordinator gyros are dual-powered and can be driven by either air or electricity.

Rather than using a needle as an indicator, the gimbal moves a dial on which is the rear view of a symbolic aircraft. The bezel of the instrument is marked to show wings-level flight and bank angles for a standard-rate turn. [Figure 3-34]

Figure 3-34. *A turn coordinator senses rotation about both the roll and yaw axes.*

Doghouse: A mark on the dial of a turn-and-slip indicator that has the shape of a doghouse.

The inclinometer, similar to the one in a turn-and-slip indicator, is called a coordination ball, which shows the relationship between the bank angle and the rate of yaw. The turn is coordinated when the ball is in the center, between the marks. The aircraft is skidding when the ball rolls toward the outside of the turn and is slipping when it moves toward the inside of the turn.

A turn coordinator does not sense pitch. This is indicated on some instruments by placing the words "NO PITCH INFORMATION" on the dial.

Flight Director Systems

Horizontal Situation Indicator (HSI)

The HSI is a direction indicator that uses the output from a flux valve to drive the dial, which acts as the compass card. This instrument, shown in figure 3-35, combines the magnetic compass with navigation signals and a glide slope. This gives the pilot an indication of the location of the aircraft with relationship to the chosen course.

Figure 3-35. *Horizontal situation indicator (HSI).*

In figure 3-35, the aircraft heading displayed on the rotating azimuth card under the upper lubber line is 175°. The course-indicating arrowhead shown is set to 205°; the tail indicates the reciprocal, 025°. The course deviation bar operates with a VOR/Localizer (VOR/LOC) navigation receiver to indicate left or right deviations from the course selected with the course-indicating arrow, operating in the same manner that the angular movement of a conventional VOR/LOC needle indicates deviation from course.

The desired course is selected by rotating the course-indicating arrow in relation to the azimuth card by means of the course select knob. This gives you a pictorial presentation: the fixed aircraft symbol and course deviation bar display the aircraft relative to the selected course, as though you were above the aircraft looking down. The TO/FROM indicator is a triangular-shaped pointer. When the indicator points to the head of the course arrow, it shows that the course selected, if properly intercepted and flown, will take the aircraft to the selected facility. When the indicator points to the tail of the course arrow, it shows that the course selected, if properly intercepted and flown, will take the aircraft directly away from the selected facility.

The glide-slope deviation pointer indicates the relation of the aircraft to the glide slope. When the pointer is below the center position, the aircraft is above the glide slope, and an increased rate of descent is required. In some installations, the azimuth card is a remote indicating compass; however, in others the heading must be checked against the magnetic compass occasionally and reset with the course select knob.

Attitude Director Indicator (ADI)

Advances in attitude instrumentation combine the gyro horizon with other instruments such as the HSI, thereby reducing the number of separate instruments the pilot must devote attention to. The attitude director indicator (ADI) is an example of such an advancement upon the attitude indicator. An integrated flight director system consists of electronic components that compute and indicate the aircraft attitude required to attain and maintain a preselected flight condition.

The ADI in figure 3-36 furnishes the same information as an attitude indicator, but has the additional feature of a set of computer-driven bowtie-shaped steering bars. Instead of the symbolic aircraft, a delta-shaped symbol represents the aircraft being flown.

The mode controller provides signals through the ADI to drive the steering bars. The pilot flies the aircraft to place the delta symbol in the V of the steering bars. "Command" indicators tell the pilot in which direction and how much to change aircraft attitude to achieve the desired result. The computed command indications relieve the pilot of many of the mental calculations required for instrument flight.

The flight director/autopilot system described below is typical of installations in some of the more complex general aviation aircraft. The components in the instrument panel include the mode controller, ADI, HSI, and annunciator panel. These units are illustrated in figure 3-36.

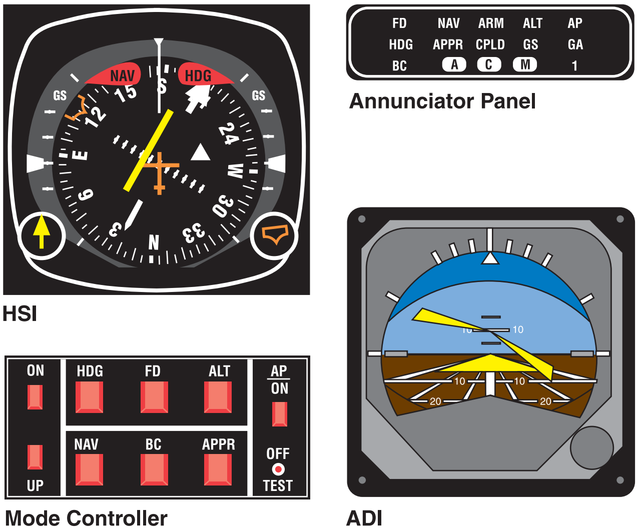


Figure 3-36. *Integrated flight system.*

The mode controller has six pushbutton switches for turning on the flight director system and selection of all modes, a switch for autopilot engagement, a trim switch, and a preflight test button. The ADI displays information regarding pitch-and-roll attitude, pitch-and-roll commands, and decision altitude (when used with a radar altimeter).

The HSI displays slaved gyro magnetic heading information, VOR/LOC/area navigation (RNAV) course deviation, and glide-slope deviation indications. The annunciator panel displays all vertical and lateral flight director/autopilot modes, including all "armed" modes prior to capture. Simply stated, it tells the pilot when the selected mode has been received and accepted by the system, and if an "armed" mode is selected, when capture has been initiated. It also has integral marker beacon lights and a trim failure warning.

A flight control guidance system that consists of either an autopilot with an approach coupler or a flight director system is required for Category II operations.

Instrument Systems Preflight Procedures

Inspecting the instrument system requires a relatively small part of the total time required for preflight activities, but its importance cannot be overemphasized. Before any flight involving aircraft control by instrument reference, you should check all instruments and their sources of power for proper operation.

Before Engine Start

1. Walk-around inspection—check the condition of all antennas and check the pitot tube for the presence of any obstructions and remove the cover. Check the static ports to be sure they are free from dirt and obstructions, and ensure there is nothing on the structure near the ports that would disturb the air flowing over them.
2. Aircraft records—confirm that the altimeter and static system has been checked and found within approved limits within the past 24-calendar months. Check the replacement date for the emergency locator transmitter (ELT) batteries noted in the maintenance record, and be sure they have been replaced within this time interval.
3. Preflight paperwork—check the Airport/Facility Directory (A/FD) and all Notices to Airmen (NOTAMs) for the condition and frequencies of all the navigation aids (NAVAIDs) that will be used on the flight. Handbooks, en route charts, approach charts, computer and flight log should be appropriate for the departure, en route, destination, and alternate airports.
4. Radio equipment—switches off.
5. Suction gauge—proper markings.
6. Airspeed indicator—proper reading.
7. Attitude indicator—uncaged, if applicable.
8. Altimeter—set the current altimeter setting and check that the pointers indicate the elevation of the airport.
9. Vertical speed indicator—zero indication.
10. Heading indicator—uncaged, if applicable.
11. Turn coordinator—miniature aircraft level, ball approximately centered (level terrain).
12. Magnetic compass—full of fluid and the correction card is in place and current.
13. Clock—set to the correct time.
14. Engine instruments—proper markings and readings.
15. Deicing and anti-icing equipment—check availability and fluid quantity.
16. Alternate static-source valve—be sure it can be opened if needed, and that it is fully closed.
17. Pitot tube heater—watch the ammeter when it is turned on, or by using the method specified in the POH/AFM.

After Engine Start

1. When you turn the master switch on—listen to the gyros as they spin up. Any hesitation or unusual noises should be investigated before flight.
2. Suction gauge or electrical indicators—check the source of power for the gyro instruments. The suction developed should be appropriate for the instruments in that particular aircraft. If the gyros are electrically driven, check the generators and inverters for proper operation.
3. Magnetic compass—check the card for freedom of movement and confirm the bowl is full of fluid. Determine compass accuracy by comparing the indicated heading against a known heading (runway heading) while the airplane is stopped or taxiing straight. Remote indicating compasses should also be checked against known headings. Note the compass card correction for the takeoff runway heading.
4. Heading indicator—allow 5 minutes after starting engines for the gyro to spin up. Before taxiing, or while taxiing straight, set the heading indicator to correspond with the magnetic compass heading. A slaved gyro compass should be checked for slaving action and its indications compared with those of the magnetic compass.
5. Attitude indicator—allow the same time as noted above for gyros to spin up. If the horizon bar erects to the horizontal position and remains at the correct position for the attitude of the airplane, or if it begins to vibrate after this attitude is reached and then slowly stops vibrating altogether, the instrument is operating properly.
6. Altimeter—with the altimeter set to the current reported altimeter setting, note any variation between the known field elevation and the altimeter indication. If the variation is on the order of 75 feet, the accuracy of the altimeter is questionable and the problem should be referred to a repair station for evaluation and possible correction. Because the elevation of the ramp or hangar area might differ significantly from field elevation, recheck when in the runup area if the error exceeds 75 feet. When no altimeter setting is available, set the altimeter to the published field elevation during the preflight instrument check.
7. Vertical speed indicator—the instrument should read zero. If it does not, tap the panel gently. If it stays off the zero reading and is not adjustable, the ground indication will have to be interpreted as the zero position in flight.
8. Carburetor heat—check for proper operation and return to cold position.
9. Engine instruments—check for proper readings.
10. Radio equipment—check for proper operation and set as desired.
11. Deicing and anti-icing equipment—check operation.

Taxiing and Takeoff

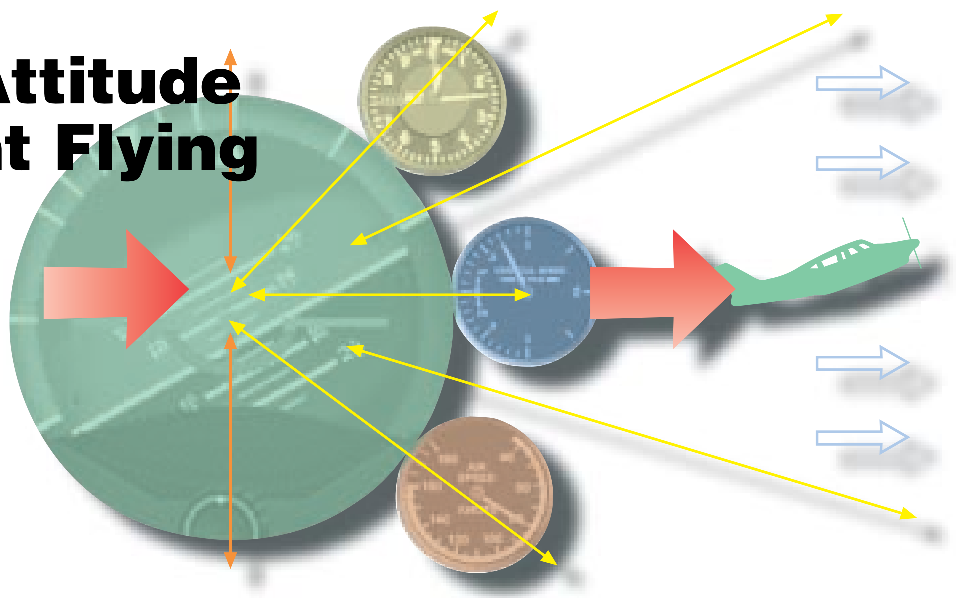
1. Turn coordinator—during taxi turns, check the miniature aircraft for proper turn indications. The ball should move freely. The ball should move opposite to the direction of turns. The turn instrument should indicate in the direction of the turn. While taxiing straight, the miniature aircraft should be level.
2. Heading indicator—before takeoff, recheck the heading indicator. If your magnetic compass and deviation card are accurate, the heading indicator should show the known taxiway or runway direction when the airplane is aligned with them (within 5°).
3. Attitude indicator—if the horizon bar fails to remain in the horizontal position during straight taxiing, or tips in excess of 5° during taxi turns, the instrument is unreliable. Adjust the miniature aircraft with reference to the horizon bar for the particular airplane while on the ground. For some tricycle-gear airplanes, a slightly nose-low attitude on the ground will give a level flight attitude at normal cruising speed.

Engine Shut Down

When shutting down the engine, note any abnormal instrument indications.

Chapter 4

Airplane Attitude Instrument Flying



Introduction

Attitude instrument flying may be defined as the control of an aircraft's spatial position by using instruments rather than outside visual references.

Any flight, regardless of the aircraft used or route flown, consists of basic maneuvers. In visual flight, you control aircraft attitude with relation to the natural horizon by using certain reference points on the aircraft. In instrument flight, you control aircraft attitude by reference to the flight instruments. A proper interpretation of the flight instruments will give you essentially the same information that outside references do in visual flight. Once you learn the role of all the instruments in establishing and maintaining a desired aircraft attitude, you will be better equipped to control the aircraft in emergency situations involving failure of one or more key instruments.

Two basic methods used for learning attitude instrument flying are "control and performance" and "primary and supporting." Both methods involve the use of the same instruments, and both use the same responses for attitude control. They differ in their reliance on the attitude indicator and interpretation of other instruments.

Attitude instrument flying: Controlling the aircraft by reference to the instruments rather than outside visual cues.

Control and Performance Method

Aircraft performance is achieved by controlling the aircraft attitude and power (angle of attack and thrust to drag relationship). Aircraft attitude is the relationship of its longitudinal and lateral axes to the Earth's horizon. An aircraft is flown in instrument flight by controlling the attitude and power, as necessary, to produce the desired performance. This is known as the control and performance method of attitude instrument flying and can be applied to any basic instrument maneuver. [Figure 4-1] The three general categories of instruments are control, performance, and navigation instruments.

Control Instruments

The control instruments display immediate attitude and power indications and are calibrated to permit attitude and power adjustments in precise amounts. 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 indicator and power indicators. These power indicators vary with aircraft and may include tachometers, manifold pressure, engine pressure ratio, fuel flow, etc.

Instrument flight fundamental:
Attitude + Power = Performance

Figure 4-1. *Control/Performance cross-check method.*

Performance Instruments

The performance instruments indicate the aircraft's actual performance. Performance is determined by reference to the altimeter, airspeed or Mach indicator, vertical speed indicator, heading indicator, angle-of-attack indicator, and turn-and-slip indicator.

Navigation Instruments

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, glide-slope indicators, and bearing pointers.

Procedural Steps

1. Establish—Establish an attitude and power setting on the control instruments that will result in the desired performance. Known or computed attitude changes and approximate power settings will help to reduce the pilot's workload.

2. **Trim**—Trim until control pressures are neutralized. Trimming for hands-off flight is essential for smooth, precise aircraft control. It allows pilots to divert their attention to other cockpit duties with minimum deviation from the desired attitude.

Trim: Adjusting the aerodynamic forces on the control surfaces so that the aircraft maintains the set attitude without any control input.

3. Cross-check— 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—Adjust the attitude or power setting on the control instruments as necessary.

Attitude Control

Proper control of aircraft attitude is the result of maintaining a constant attitude, knowing when and how much to change the attitude, and smoothly changing the attitude a precise amount. Aircraft attitude control is accomplished by properly using the attitude indicator. The attitude reference provides an immediate, direct, and corresponding indication of any change in aircraft pitch or bank attitude.

Pitch Control

Pitch changes are made by changing the "pitch attitude" of the miniature aircraft or fuselage dot by precise amounts in relation to the horizon. 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 will determine 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 may be located at the top or bottom of the attitude reference. Normally, use a bank angle that 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.

From experience in an aircraft, you know approximately how far to move the throttles to change the power a given amount. Therefore, you can make power changes primarily by throttle movement and then cross-check the indicators to establish a more precise setting. The key is to avoid **fixating** on the indicators while setting the power. A knowledge of approximate power settings for various **flight configurations** will help you avoid overcontrolling power.

Primary and Supporting Method

Another basic method for presenting 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. [Figure 4-2] Instruments are grouped as they relate to control function and aircraft performance as follows:

Pitch Instruments

Attitude Indicator
Altimeter
Airspeed Indicator
Vertical Speed Indicator

Bank Instruments

Attitude Indicator
Heading Indicator
Magnetic Compass
Turn Coordinator

Power Instruments

Airspeed Indicator
Engine Instruments
- Manifold Pressure Gauge (MP)
- Tachometer/RPM
- Engine Pressure Ratio (EPR)—Jet

For any maneuver or condition of flight, the pitch, bank, and power control requirements are most clearly indicated by certain key instruments. The instruments that provide the most pertinent and essential information will be referred to as primary instruments. Supporting instruments back up and supplement the information shown on the primary

Fixating: Staring at a single instrument, thereby interrupting the cross-check process.

Flight configurations: Adjusting the aircraft controls surfaces (including flaps and landing gear) in a manner that will achieve a specified attitude.

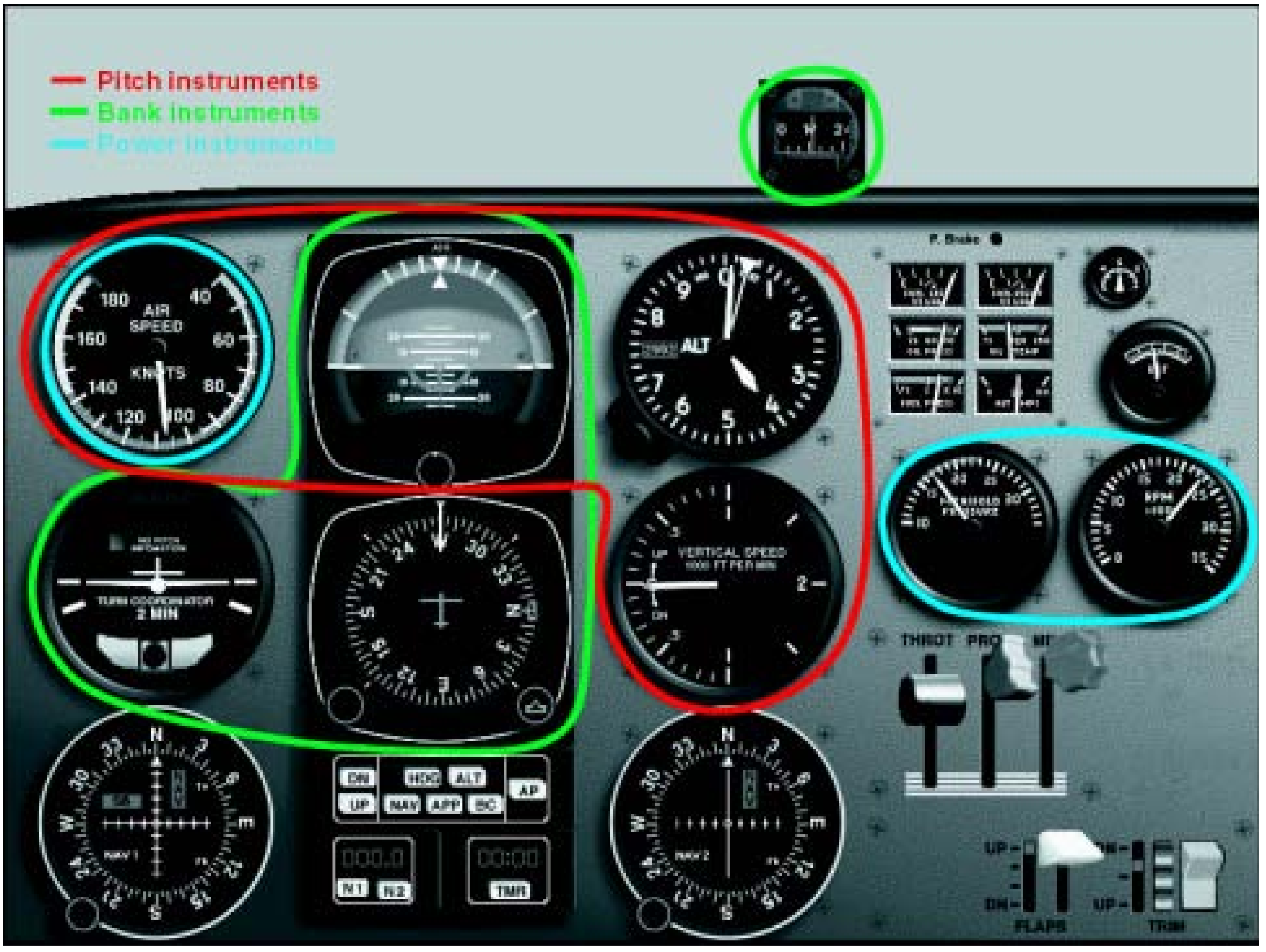


Figure 4-2. *Primary/Supporting cross-check method.*

instruments. Straight-and-level flight at a constant airspeed, for example, means that an exact altitude is to be maintained with zero bank (constant heading) at a constant airspeed. The pitch, bank, and power instruments that tell you whether you are maintaining this flight condition are the:

1. Altimeter—supplies the most pertinent altitude information and is therefore primary for pitch.
2. Heading Indicator—supplies the most pertinent bank or heading information, and is primary for bank.
3. 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, this concept of primary and supporting instruments does not devalue any particular flight instrument. It is the only instrument that portrays instantly and directly the actual flight attitude. It should always be used, when available, in establishing and maintaining pitch-and-bank attitudes. You will better understand the specific use of primary and supporting instruments when the basic instrument maneuvers are presented in detail in Chapter 5, "Airplane Basic Flight Maneuvers."

You will find the terms "direct indicating instrument" and "indirect indicating instrument" used in the following pages. A "direct" indication is the true and instantaneous reflection of airplane pitch-and-bank attitude by the miniature aircraft relative to the horizon bar of the attitude indicator. The altimeter, airspeed indicator, and vertical speed indicator give supporting ("indirect") indications of pitch attitude at a given power setting. The heading indicator and turn needle give supporting indications for bank attitude.

Fundamental Skills

During attitude instrument training, you must develop three fundamental skills involved in all instrument flight maneuvers: instrument cross-check, instrument interpretation, and aircraft control. Although you learn these skills separately and in deliberate sequence, a measure of your proficiency in precision flying will be your ability to integrate these skills into unified, smooth, positive control responses to maintain any prescribed flight path.

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 that will produce the desired result in performance. 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.

Selected Radial Cross-Check

When you use the selected radial cross-check, your eyes spend 80 to 90 percent of the time looking at the attitude indicator, leaving it only to take a quick glance at one of the flight instruments (for this discussion, the five instruments surrounding the attitude indicator will be called the flight instruments). With this method, your 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 4-3]

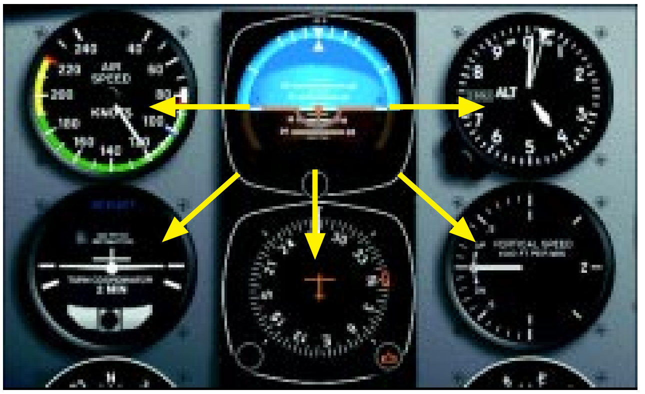


Figure 4-3. *Selected radial cross-check pattern.*

Inverted-V Cross-Check

Moving your eyes from the attitude indicator down to the turn instrument, up to the attitude indicator, down to the vertical speed indicator, and back up to the attitude indicator is called the inverted-V cross-check. [Figure 4-4]

Figure 4-4. *Inverted-V cross-check.*

The Rectangular Cross-Check

If you move your eyes across the top three instruments (airspeed indicator, attitude indicator, and altimeter) and drop them down to scan the bottom three instruments (vertical speed indicator, heading indicator, and turn instrument), their path will describe a rectangle (clockwise or counterclockwise rotation is a personal choice). [Figure 4-5]

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 for your eyes to return to an instrument critical to the successful completion of the maneuver.

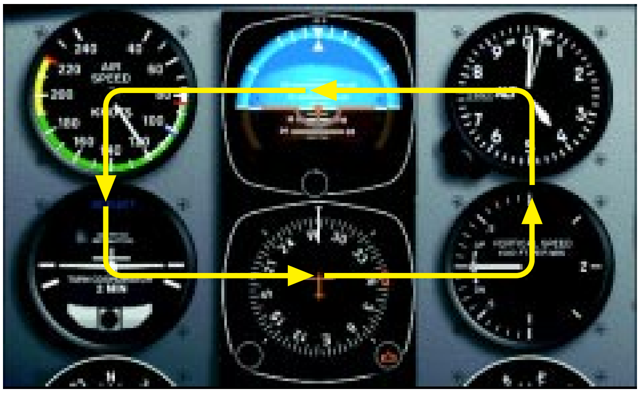


Figure 4-5. *Rectangular cross-check pattern.*

Common Cross-Check Errors

As a beginner, you might cross-check rapidly, looking at the instruments without knowing exactly what you are looking for. With increasing experience in basic instrument maneuvers and familiarity with the instrument indications associated with them, you will learn what to look for, when to look for it, and what response to make. As proficiency increases, you cross-check primarily from habit, suiting your scanning rate and sequence to the demands of the flight situation.

You can expect to make many of the following common scanning errors, both during training and at any subsequent time, if you fail to maintain basic instrument proficiency through practice:

1. Fixation, or staring at a single instrument, usually occurs for a good reason, but has poor results. For instance, you may find yourself staring at your altimeter, which reads 200 feet below the assigned altitude, wondering how the needle got there. While you gaze at the instrument, perhaps with increasing **tension** on the controls, a heading change occurs unnoticed, and more errors accumulate.

   Another common fixation is likely when you initiate an attitude change. For example, you establish a shallow bank for a 90° turn and stare at the heading indicator throughout the turn, instead of maintaining your cross-check of other pertinent instruments. You know the aircraft is turning and you do not need to recheck the heading indicator for approximately 25 seconds after turn entry, yet you cannot take your eyes off the instrument. The problem here may not be entirely due to cross-check error. It may be related to difficulties with one or both of the other fundamental skills. You may be fixating because of uncertainty about reading the heading indicator (interpretation), or because of inconsistency in rolling out of turns (control).
2. Omission of an instrument from your cross-check is another likely fault. It may be caused by failure to anticipate significant instrument indications following attitude changes. For example, on your roll-out from a 180° steep turn, you establish straight-and-level flight with reference to the attitude indicator alone, neglecting to check the heading indicator for constant heading information. Because of precession error, the attitude indicator will temporarily show a slight error, correctable by quick reference to the other flight instruments.
3. 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. You naturally tend to rely on the instrument that you understand most readily, even when it provides erroneous or inadequate information. Reliance on a single instrument is poor technique. For example, you can maintain reasonably close altitude control with the attitude indicator, but you cannot hold altitude with precision without including the altimeter in your cross-check.

Instrument Interpretation

The second fundamental skill, instrument interpretation, requires the most thorough study and analysis. It begins as you understand each instrument's construction and operating principles. Then you must apply this knowledge to the performance of the aircraft that you are flying, the particular maneuvers to be executed, the cross-check and control techniques applicable to that aircraft, and the flight conditions in which you are operating.

Tension: Maintaining an excessively strong grip on the control column; usually results in an overcontrolled situation.

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 4-6] The airplane is climbing at 500 feet per minute (fpm) as shown on the vertical speed indicator, and at an 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.

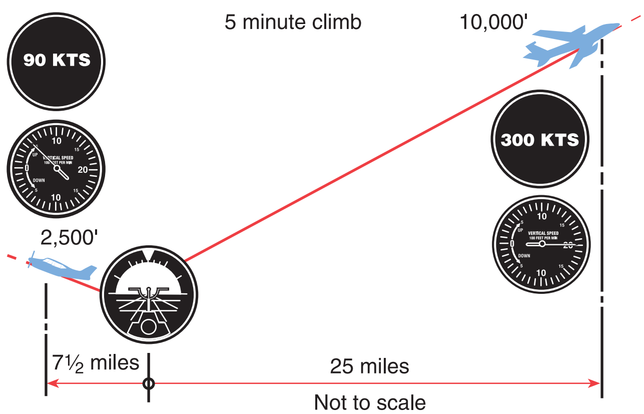


Figure 4-6. *Power and attitude equal performance.*

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 vertical speed indicator in the jet reads 2,000 fpm, and the airspeed indicates 300 knots. As you learn the performance capabilities of the aircraft in which you are training, you will interpret the instrument indications appropriately in terms of the attitude of the aircraft. If the pitch attitude is to be determined, the airspeed indicator, altimeter, vertical speed indicator, 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, you will learn what performance to expect and the combination of instruments you must interpret in order to control aircraft attitude during the maneuver.

Aircraft Control

The third fundamental instrument flying skill is aircraft control. When you use instruments as substitutes for outside references, the necessary control responses and thought processes are the same as those for controlling aircraft performance by means of outside references. Knowing the desired attitude of the aircraft with respect to the natural and artificial horizon, you maintain the attitude or change it by moving the appropriate controls.

Aircraft control is composed of four components: pitch control, bank control, power control, and trim.

1. 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, you exert control pressures to effect the desired pitch attitude with reference to the horizon.

2. Bank control is controlling the angle made by the wing and the horizon. After interpreting the bank attitude from the appropriate instruments, you exert the necessary pressures to move the ailerons and roll the aircraft about the longitudinal axis.

3. Power control is used when interpretation of the flight instruments indicates a need for a change in thrust.

4. Trim is used to relieve all control pressures held after a desired attitude has been attained. An improperly trimmed aircraft requires constant control pressures, produces tension, distracts your attention from cross-checking, and contributes to abrupt and erratic attitude control. The pressures you feel on the controls must be those you apply while controlling a planned change in aircraft attitude, not pressures held because you let the aircraft control you.

Chapter 5

Airplane Basic Flight Maneuvers

Introduction

Instrument flying **techniques** differ according to aircraft type, class, performance capability, and instrumentation. Therefore, the procedures and techniques that follow will need to be modified for application to different types of aircraft. Recommended procedures, performance data, operating limitations, and flight characteristics of a particular aircraft are available in your Pilot's Operating Handbook/Airplane Flight Manual (POH/AFM) for study before practicing the flight maneuvers.

The flight maneuvers discussed here assume the use of a single-engine, propeller-driven **small airplane** with retractable gear and flaps and a panel with instruments representative of those discussed earlier in Chapter 3, "Flight Instruments." With the exception of the instrument takeoff, all of the maneuvers can be performed on "partial panel," with the attitude gyro and heading indicator covered or inoperative.

Straight-and-Level Flight

Pitch Control

The pitch attitude of an airplane is the angle between the longitudinal axis of the airplane and the actual horizon. In level flight, the pitch attitude varies with airspeed and load. For training purposes, the latter factor can normally be disregarded in small airplanes. At a constant airspeed, there is only one specific pitch attitude for level flight. At slow cruise speeds, the level-flight attitude is nose-high; at fast cruise speeds, the level-flight attitude is nose-low. [Figures 5-1 and 5-2] Figure 5-3 shows the attitude at normal cruise speeds.

The pitch instruments are the attitude indicator, the altimeter, the vertical speed indicator, and the airspeed indicator.

Attitude Indicator

The attitude indicator gives you a **direct indication** of pitch attitude. You attain the desired pitch attitude by using the elevator control to raise or lower the miniature aircraft in relation to the horizon bar. This corresponds to the way you adjust pitch attitude in visual flight by raising or lowering the nose of the airplane in relation to the natural horizon. However, unless the airspeed is constant, and until you have established and identified the level-flight attitude for that airspeed, you have no way of knowing whether level flight, as indicated on the attitude indicator, is resulting in level flight as shown on the altimeter, vertical speed indicator, and airspeed indicator. If the miniature aircraft of the attitude indicator is properly adjusted on the ground before takeoff, it will show approximately level flight at normal cruise speed when you complete your level-off from a climb. If further adjustment of the miniature aircraft is necessary, the other pitch instruments must be used to maintain level flight while the adjustment is made.

Technique: The manner or style in which the procedures are executed.

Small airplane: An airplane of 12,500 pounds or less maximum certificated takeoff weight.

Direct indication: The true and instantaneous reflection of aircraft pitch-and-bank attitude by the miniature aircraft, relative to the horizon bar of the attitude indicator.

Figure 5-1. *Pitch attitude and airspeed in level flight, slow cruise speed.*

Figure 5-2. *Pitch attitude and airspeed in level flight, fast cruise speed.*

Figure 5-3. *Pitch attitude and airspeed in level flight, normal cruise speed.*

In practicing pitch control for level flight using only the attitude indicator, restrict the displacement of the horizon bar to a bar width up or down, a half-bar width, then a one-and-one-half bar width. Half-, two-, and three-bar-width nose-high attitudes are shown in figures 5-4, 5-5, and 5-6.

Your instructor pilot may demonstrate these normal pitch corrections while you compare the indications on the attitude indicator with the airplane's position to the natural horizon.

Figure 5-4. *Pitch correction for level flight, half-bar width.*

Pitch attitude changes for corrections to level flight by reference to instruments are much smaller than those commonly used for visual flight. With the airplane correctly trimmed for level flight, the elevator displacement and the **control pressures** necessary to effect these standard pitch changes are usually very slight. Following are a few helpful hints to help you determine how much elevator control pressure is required.

Figure 5-5. *Pitch correction for level flight, two-bar width.*

Control pressures: The amount of physical exertion on the control column necessary to achieve the desired aircraft attitude.

Figure 5-6. *Pitch correction for level flight, three-bar width.*

Figure 5-7. *Using the altimeter for pitch interpretation, a high altitude means a nose-high pitch attitude.*

Figure 5-8. *Pitch correction following altitude increase—lower nose to correct altitude error.*

First, a tight grip on the controls makes it difficult to feel control pressure changes. Relaxing and learning to control "with your eyes and your head" instead of your muscles usually takes considerable conscious effort during the early stages of instrument training.

Second, make smooth and small pitch changes with a positive pressure. Practice these small corrections until you can make pitch corrections up or down, "freezing" (holding constant) the one-half, full, and one-and-one-half bar widths on the attitude indicator.

Third, with the airplane properly trimmed for level flight, momentarily release all of your pressure on the elevator control when you become aware of tenseness. This will remind you that the airplane is stable; except under turbulent conditions, it will maintain level flight if you leave it alone. Even when your eyes tell you that no control change is called for, it will be difficult to resist the impulse to move the controls. This may prove to be one of your most difficult initial training problems.

Altimeter

At constant power, any deviation from level flight (except in turbulent air) must be the result of a pitch change. Therefore, the altimeter gives an **indirect indication** of the pitch attitude in level flight, assuming constant power. Since the altitude should remain constant when the airplane is in level flight, any deviation from the desired altitude signals the need for a pitch change. If you are gaining altitude, the nose must be lowered. [Figures 5-7 and 5-8]

Indirect indication: A reflection of aircraft pitch-and-bank attitude by the instruments other than the attitude indicator.

The rate of movement of the altimeter needle is as important as its direction of movement for maintaining level flight without the use of the attitude indicator. An excessive pitch deviation from level flight results in a relatively rapid change of altitude; a slight pitch deviation causes a slow change. Thus, if the altimeter needle moves rapidly clockwise, assume a considerable nose-high deviation from level-flight attitude. Conversely, if the needle moves slowly counterclockwise to indicate a slightly nose-low attitude, assume that the pitch correction necessary to regain the desired altitude is small. As you add the altimeter to the attitude indicator in your cross-check, you will learn to recognize the rate of movement of the altimeter needle for a given pitch change as shown on the attitude indicator.

If you are practicing precision control of pitch in an airplane without an attitude indicator, make small pitch changes by visual reference to the natural horizon, and note the rate of movement of the altimeter. Note what amount of pitch change gives the slowest steady rate of change on the altimeter. Then practice small pitch corrections by accurately interpreting and controlling the rate of needle movement.

Your instructor pilot may demonstrate an excessive nose-down deviation (indicated by rapid movement of the altimeter needle) and then, as an example, show you the result of improper corrective technique. The normal impulse is to make a large pitch correction in a hurry, but this inevitably leads to **overcontrolling**. The needle slows down, then reverses direction, and finally indicates an excessive nose-high deviation. The result is tension on the controls, erratic control response, and increasingly extreme control movements. The correct technique, which is slower and smoother, will return the airplane to the desired attitude more quickly, with positive control and no confusion.

When a pitch error is detected, corrective action should be taken promptly, but with light control pressures and two distinct changes of attitude: (1) a change of attitude to stop the needle movement, and (2) a change of attitude to return to the desired altitude.

When you observe that the needle movement indicates an altitude deviation, apply just enough elevator pressure to slow down the rate of needle movement. If it slows down abruptly, ease off some of the pressure until the needle continues to move, but slowly. Slow needle movement means your airplane attitude is close to level flight. Add a little more corrective pressure to stop the direction of needle movement. At this point you are in level flight; a reversal of needle movement means you have passed through it. Relax your control pressures carefully as you continue to cross-check, since changing airspeed will cause changes in the effectiveness of a given control pressure. Next, adjust the pitch attitude with elevator pressure for the rate of change of altimeter needle movement that you have correlated with normal pitch corrections, and return to the desired altitude.

As a rule of thumb, for errors of less than 100 feet, use a half-bar-width correction. [Figures 5-9 and 5-10] For errors in excess of 100 feet, use an initial full-bar-width correction. [Figures 5-11 and 5-12]

Practice predetermined altitude changes using the altimeter alone, then in combination with the attitude indicator.

Overcontrolling: Using more movement in the control column than is necessary to achieve the desired pitch-and-bank condition.

Figure 5-9. *Altitude error, less than 100 feet.*

Figure 5-10. *Pitch correction, less than 100 feet—1/2 bar low to correct altitude error.*

Figure 5-11. *Altitude error, greater than 100 feet.*

Figure 5-12. *Pitch correction, greater than 100 feet—1 bar correction initially.*

Vertical Speed Indicator

The vertical speed indicator gives an indirect indication of pitch attitude and is both a **trend** and a rate instrument. As a trend instrument, it shows immediately the initial vertical movement of the airplane, which, disregarding turbulence, can be considered a reflection of pitch change. To maintain level flight, use the vertical speed indicator in conjunction with the altimeter and attitude indicator. Note any "up" or "down" trend of the needle from zero and apply a very light corrective elevator pressure. As the needle returns to zero, relax the corrective pressure. If your control pressures have been smooth and light, the needle will react immediately and slowly, and the altimeter will show little or no change of altitude.

Used as a rate instrument, the **lag** characteristics of the vertical speed indicator must be considered.

Lag refers to the delay involved before the needle attains a stable indication following a pitch change. Lag is directly proportional to the speed and magnitude of a pitch change. If a slow, smooth pitch change is initiated, the needle will move with minimum lag to a point of deflection corresponding to the extent of the pitch change, and then stabilize as the aerodynamic forces are balanced in the climb or descent. A large and abrupt pitch change will produce erratic needle movement, a reverse indication, and introduce greater time delay (lag) before the needle stabilizes. Pilots are cautioned not to chase the needle when flight through turbulent conditions produces erratic needle movements.

When using the vertical speed indicator as a rate instrument and combining it with the altimeter and attitude indicator to maintain level flight, keep this in mind: the amount the altimeter has moved from the desired altitude governs the rate at which you should return to that altitude. A rule of thumb is to make an attitude change that will result in a vertical-speed rate approximately double your error in altitude. For example, if altitude is off by 100 feet, your rate of return should be approximately 200 feet per minute (fpm). If it is off more than 100 feet, the correction should be correspondingly greater, but should never exceed the optimum rate of climb or descent for your airplane at a given airspeed and configuration.

A deviation more than 200 fpm from the desired rate of return is considered overcontrolling. For example, if you are attempting to return to an altitude at a rate of 200 fpm, a rate in excess of 400 fpm indicates overcontrolling.

When you are returning to an altitude, the vertical speed indicator is the primary pitch instrument. Occasionally, the vertical speed indicator is slightly out of calibration and may indicate a climb or descent when the airplane is in level flight. If you cannot adjust the instrument, you must take the error into consideration when using it for pitch control. For example, if the needle indicates a descent of 200 fpm while in level flight, use this indication as the zero position.

Airspeed Indicator

The airspeed indicator presents an indirect indication of the pitch attitude. At a constant power setting and pitch attitude, airspeed remains constant. [Figure 5-13] As the pitch attitude lowers, airspeed increases, and the nose should be raised. [Figure 5-14] As the pitch attitude rises, airspeed decreases,

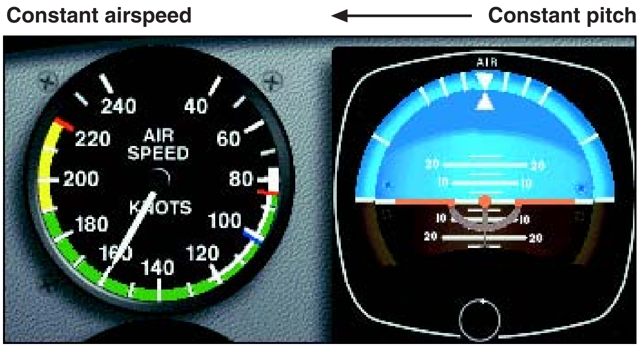


Figure 5-13. *Constant power plus constant pitch equals constant airspeed.*

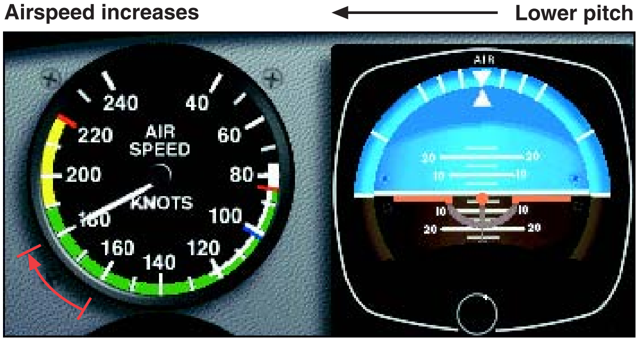


Figure 5-14. *Constant power plus decreased pitch equals increased airspeed.*

Trend: Instruments showing an immediate indication of the direction of aircraft movement.

Lag: The delay that occurs before an instrument needle attains a stable indication.

and the nose should be lowered. [Figure 5-15] A rapid change in airspeed indicates a large pitch change, and a slow change of airspeed indicates a small pitch change.

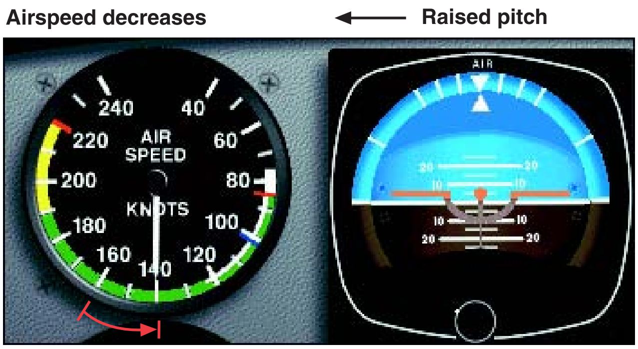


Figure 5-15. *Constant power plus increased pitch equals decreased airspeed.*

The apparent lag in airspeed indications with pitch changes varies greatly among different airplanes and is due to the time required for the airplane to accelerate or decelerate when the pitch attitude is changed. There is no appreciable lag due to the construction or operation of the instrument. Small pitch changes, smoothly executed, result in an immediate change of airspeed.

Pitch control in level flight is a question of cross-check and interpretation of the instrument panel for the instrument information that will enable you to visualize and control pitch attitude. Regardless of individual differences in cross-check technique, all pilots should use the instruments that give the best information for controlling the airplane in any given maneuver. Pilots should also check the other instruments to aid in maintaining the important, or primary, instruments at the desired indication.

As noted previously, the primary instrument is the one that gives the most pertinent information for any particular maneuver. It is usually the one you should hold at a constant indication. Which instrument is primary for pitch control in level flight, for example? This question should be considered in the context of specific airplane, weather conditions, pilot experience, operational conditions, and other factors. Attitude changes must be detected and interpreted instantly for immediate control action in high-performance airplanes. On the other hand, a reasonably proficient instrument pilot in a slower airplane may rely more on the altimeter for primary pitch information, especially if it is determined that too much reliance on the attitude indicator fails to provide the necessary precise attitude information. Whether the pilot decides to regard the altimeter or the attitude indicator as primary depends on which approach will best help control the attitude.

In this handbook, the altimeter is normally considered as the primary pitch instrument during level flight.

Bank Control

The bank attitude of an airplane is the angle between the lateral axis of the airplane and the natural horizon. To maintain a straight-and-level flight path, you must keep the wings of the airplane level with the horizon (assuming the airplane is in **coordinated** flight). Any deviation from straight flight resulting from bank error should be corrected by coordinated aileron and rudder pressure.

The instruments used for bank control are the attitude indicator, the heading indicator, and the turn coordinator. [Figure 5-16]

Attitude Indicator

The attitude indicator shows any change in bank attitude directly and instantly. On the standard attitude indicator, the angle of bank is shown pictorially by the relationship of the miniature aircraft to the artificial horizon bar, and by the alignment of the pointer with the banking scale at the top of the instrument. On the face of the standard 3-inch instrument, small angles of bank can be difficult to detect by reference to the miniature aircraft, especially if you lean to one side or move your seating position slightly. The position of the scale pointer is a good check against the apparent miniature aircraft position. Disregarding **precession error**, small deviations from straight coordinated flight can be readily detected on the scale pointer. The banking index may be graduated as shown in figure 5-17, or it may lack the 10° and 20° indexes.

Coordinated: Using the controls to maintain or establish various conditions of flight with (1) a minimum disturbance of the forces maintaining equilibrium, or (2) the control action necessary to effect the smoothest changes in equilibrium.

Precession error: The result of the force applied to a spinning gyroscope felt not at the point the force is applied, but at a point 90° in the direction of rotation from that point.

Figure 5-16. *Instruments used for bank control.*

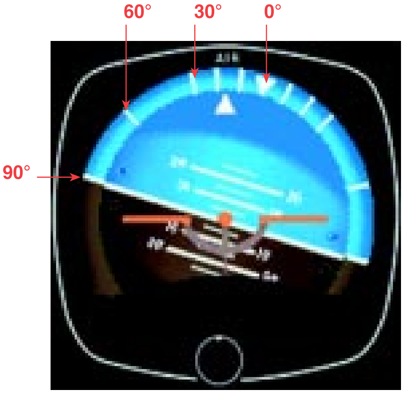


Figure 5-17. *Bank interpretation with the attitude indicator.*

The instrument depicted in figure 5-17 has a scale pointer that moves in the same direction of bank shown by the miniature aircraft. On some attitude indicators, the scale pointer moves in a direction opposite to the direction of bank shown by the miniature aircraft. A bank indication of 30° to the right of the zero, or nose position, indicates a 30° left banking attitude. Errors due to the construction of this instrument are common and predictable, but the obvious advantage of the attitude indicator is that you get an immediate indication of both pitch attitude and bank attitude in a single glance. Even with the precession errors associated with many attitude indicators, the quick attitude presentation requires less visual effort and time for positive control than other flight instruments.

Heading Indicator

The bank attitude of an aircraft in coordinated flight is shown indirectly on the heading indicator, since banking results in a turn and change in heading. Assuming the same airspeed in both instances, a rapid movement of the heading indicator needle (or azimuth card in a directional gyro) indicates a large angle of bank, whereas a slow movement of the needle or card reflects a small angle of bank. If you note the rate of movement of the heading indicator and compare it to the attitude indicator's degrees of bank, you will learn to look for important bank information on the heading indicator. This is especially the case when the attitude indicator's precession error makes a precise check of heading information necessary in order to maintain straight flight.

When you note deviations from straight flight on the heading indicator, make your correction to the desired heading using a bank angle no greater than the number of degrees to be turned. In any case, limit your bank corrections to a bank angle no greater than that required for a standard-rate turn. Use of larger bank angles requires a very high level of proficiency, and normally results in overcontrolling and erratic bank control.

Turn Coordinator

The miniature aircraft of the turn coordinator gives you an indirect indication of the bank attitude of the airplane. When the miniature aircraft is level, the airplane is in straight flight. If the ball is centered, a left deflection of the miniature aircraft means the left wing is low and the airplane is in a left turn. Thus, when the miniature aircraft is in a stabilized deflection, the airplane is turning in the direction indicated. Return to straight flight is accomplished by coordinated aileron and rudder pressure to level the miniature aircraft. Include the miniature aircraft in your cross-check and correct for even the smallest deviations from the desired position. When the instrument is used to maintain straight flight, control pressures must be applied very lightly and smoothly.

The ball of the turn coordinator is actually a separate instrument, conveniently located under the miniature aircraft because the two instruments are used together. The ball instrument indicates the quality of the turn. If the ball is off center, the airplane is slipping or skidding, and the miniature aircraft under these conditions shows an error in bank attitude. Figures 5-18 and 5-19 show the instrument indications for slips and skids, respectively. If the wings are level and the airplane is properly trimmed, the ball will remain in the center, and the airplane will be in straight flight. If the ball is not centered, the airplane is improperly trimmed (or you are holding rudder pressure against proper trim).

Figure 5-18. *Slip indication.*

Figure 5-19. *Skid indication.*

To maintain straight-and-level flight with proper trim, note the direction of ball displacement. If the ball is to the left of center and the left wing is low, apply left rudder pressure (or release right rudder pressure if you are holding it) to center the ball and correct the slip. At the same time apply right aileron pressure as necessary to level the wings, cross-checking the heading indicator and attitude indicator as you center the ball. If the wings are level and the ball is displaced from the center, the airplane is skidding. Note the direction of ball displacement, and use the same corrective technique as for an indicated slip. Center the ball (left ball/left rudder, right ball/right rudder), use aileron as necessary for bank control, and retrim.

To trim the airplane using only the turn coordinator, use aileron pressure to level the miniature aircraft and rudder pressure to center the ball. Hold these indications with control pressures, gradually releasing them as you apply rudder trim sufficient to relieve all rudder pressure. Apply aileron trim, if available, to relieve aileron pressure. With a full instrument panel, maintain a wings-level attitude by reference to all available instruments while you trim the airplane.

Power Control

Power produces thrust which, with the appropriate angle of attack of the wing, overcomes the forces of gravity, drag, and inertia to determine airplane performance.

Power control must be related to its effect on altitude and airspeed, since any change in power setting results in a change in the airspeed or the altitude of the airplane. At any given airspeed, the power setting determines whether the airplane is in level flight, in a climb, or in a descent. If you increase the power while in straight-and-level flight and hold the airspeed constant, the airplane will climb; and if you decrease the power while holding the airspeed constant, the airplane will descend. On the other hand, if you hold altitude constant, the power applied will determine the airspeed.

The relationship between altitude and airspeed determines the need for a change in pitch or power. If the airspeed is off the desired value, always check the altimeter before deciding that a power change is necessary. If you think of altitude and airspeed as interchangeable, you can trade altitude for airspeed by lowering the nose, or convert airspeed to altitude by raising the nose. If your altitude is higher than desired and your airspeed is low, or vice versa, a change in pitch alone may return the airplane to the desired altitude and airspeed. [Figure 5-20] If both airspeed and altitude are high or if both are low, then a change in both pitch and power is necessary in order to return to the desired airspeed and altitude. [Figure 5-21]

For changes in airspeed in straight-and-level flight, pitch, bank, and power must be coordinated in order to maintain constant altitude and heading. When power is changed to vary airspeed in straight-and-level flight, a single-engine, propeller-driven airplane tends to change attitude around all axes of movement. Therefore, to maintain constant altitude and heading, you will need to apply various control pressures in proportion to the change in power. When you add power to increase airspeed, the pitch instruments will show a climb unless you apply forward-elevator control pressure as the airspeed changes. When you increase power, the airplane tends to yaw and roll to the left unless you apply counteracting aileron and rudder pressures. Keeping ahead of these changes requires an increase in your cross-check speed, which varies with the type of airplane and its torque characteristics, the extent of power and speed change involved, and your technique in making the power change.

Figure 5-20. *Airspeed low and altitude high (lower pitch).*

Figure 5-21. *Airspeed and altitude high (lower pitch and reduce power).*

Power Settings

Power control and airspeed changes are much easier when you know in advance the approximate power settings necessary to maintain various airspeeds in straight-and-level flight. However, to change airspeed any appreciable amount, the common procedure is to **underpower** or **overpower** on initial power changes to accelerate the rate of airspeed change. (For small speed changes, or in airplanes that decelerate or accelerate rapidly, overpowering or underpowering is not necessary.)

Consider the example of an airplane that requires 23 inches of manifold pressure to maintain a normal cruising airspeed of 140 knots, and 18 inches of manifold pressure to maintain an airspeed of 100 knots. The reduction in airspeed from 140 knots to 100 knots while maintaining straight-and-level flight is discussed below and illustrated in figures 5-22, 5-23, and 5-24.

Instrument indications, prior to the power reduction, are shown in figure 5-22. The basic attitude is established and maintained on the attitude indicator, and the specific pitch, bank, and power control requirements are detected on these primary instruments:

Altimeter—Primary Pitch
Heading Indicator—Primary Bank
Airspeed Indicator—Primary Power

Supporting pitch-and-bank instruments are shown in the illustrations. The supporting power instrument is the manifold pressure gauge (or tachometer if the propeller is fixed-pitch).

As you make a smooth power reduction to approximately 15" Hg (underpower), the manifold pressure gauge becomes the primary power instrument. [Figure 5-23] With practice, you will be able to change a power setting with only a brief glance at the power instrument, by sensing the movement of the throttle, the change in sound, and the changes in the feel of control pressures.

Figure 5-22. *Straight-and-level flight (normal cruising speed).*

Underpower: Using less power than required for the purpose of achieving a faster rate of airspeed change.

Overpower: Using more power than required for the purpose of achieving a faster rate of airspeed change.

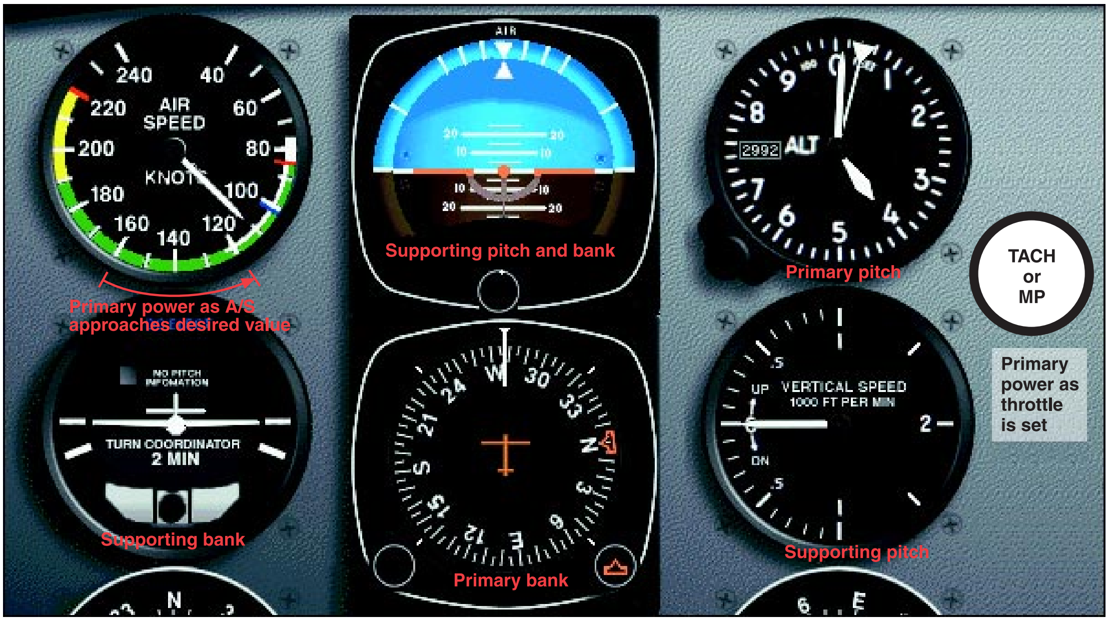


Figure 5-23. *Straight-and-level flight (airspeed decreasing).*

As the thrust decreases, increase the speed of your cross-check and be ready to apply left rudder, back-elevator, and aileron control pressure the instant the pitch-and-bank instruments show a deviation from altitude and heading. As you become proficient, you will learn to cross-check, interpret, and control the changes with no deviation of heading and altitude. Assuming smooth air and ideal control technique, as airspeed decreases, a proportionate increase in airplane pitch attitude is required to maintain altitude. Similarly, effective torque control means counteracting yaw with rudder pressure.

As the power is reduced, the altimeter is primary for pitch, the heading indicator is primary for bank, and the manifold pressure gauge is momentarily primary for power (at 15" Hg in this example). Control pressures should be trimmed off as the airplane decelerates. As the airspeed approaches the desired airspeed of 100 knots, the manifold pressure is adjusted to approximately 18" Hg and becomes the supporting power instrument. The airspeed indicator again becomes primary for power. [Figure 5-24]

Airspeed Changes in Straight-and-Level Flight

Practice of airspeed changes in straight-and-level flight provides an excellent means of developing increased proficiency in all three basic instrument skills, and brings out some common errors to be expected during training in straight-and-level flight. Having learned to control the airplane in a **clean configuration** (minimum drag conditions), you can increase your proficiency in cross-check and control by practicing speed changes while extending or retracting the flaps and landing gear. While practicing, be sure you comply with the airspeed limitations specified in your POH/AFM for gear and flap operation.

Sudden and exaggerated attitude changes may be necessary in order to maintain straight-and-level flight as the landing gear is extended and the flaps are lowered in some airplanes. The nose tends to pitch down with gear extension, and when flaps are lowered, lift increases momentarily (at partial flap settings) followed by a marked increase in drag as the flaps near maximum extension.

Clean configuration: Placing all flight control surfaces in order to create minimum drag; in most aircraft this means flaps and gear retracted.

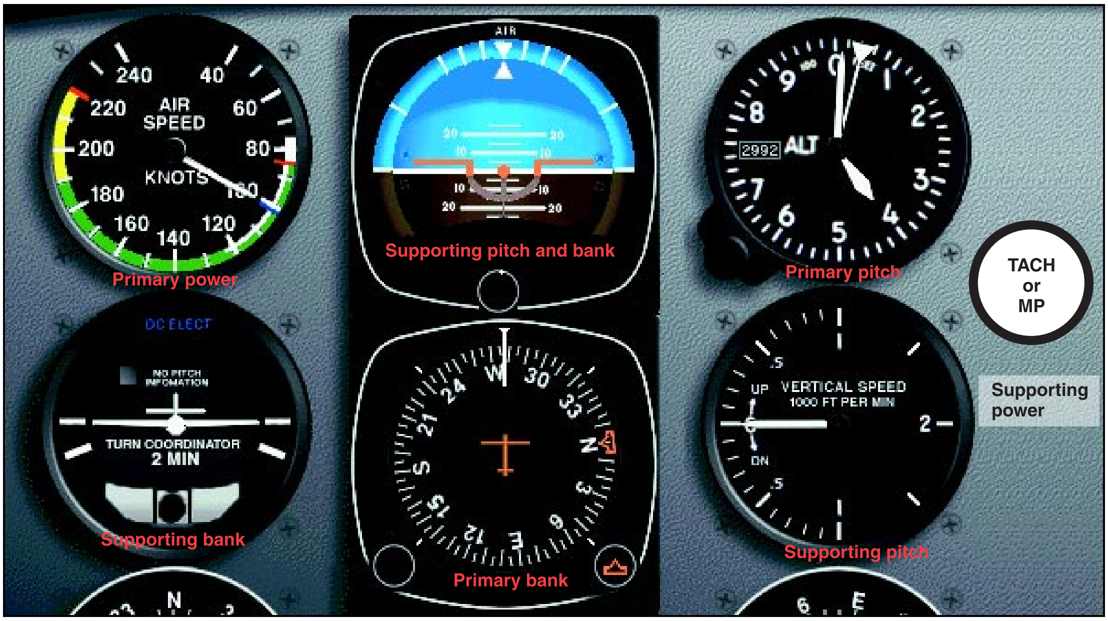


Figure 5-24. *Straight-and-level flight (reduced airspeed stabilized).*

Control technique varies according to the lift and drag characteristics of each airplane. Accordingly, knowledge of the power settings and trim changes associated with different combinations of airspeed, gear and flap configurations will reduce your instrument cross-check and interpretation problems.

For example, assume that in straight-and-level flight, an airplane indicates 145 knots with power at 22" Hg manifold pressure/2,300 RPM, gear and flaps up. After reduction in airspeed, with gear and flaps fully extended, straight-and-level flight at the same altitude requires 25" Hg manifold pressure/2,500 RPM. Maximum gear extension speed is 125 knots; maximum flap extension speed is 105 knots. Airspeed reduction to 95 knots, gear and flaps down, can be made in the following manner:

1. Increase RPM to 2,500, since a high power setting will be used in full drag configuration.

2. Reduce manifold pressure to 10" Hg. As the airspeed decreases, increase cross-check speed.

3. Make trim adjustments for an increased angle of attack and decrease in torque.

4. As you lower the gear at 125 knots, the nose may tend to pitch down and the rate of deceleration increases. Increase pitch attitude to maintain constant altitude, and trim off some of the back-elevator pressures. If you lower full flaps at this point, your cross-check, interpretation, and control must be very rapid. A less difficult technique is to stabilize the airspeed and attitude with gear down before lowering the flaps.

5. Since 18" Hg manifold pressure will hold level flight at 95 knots with the gear down, increase power smoothly to that setting as the airspeed indicator shows approximately 100 knots, and retrim. The attitude indicator now shows approximately two-and-a-half bar width nose-high in straight-and-level flight.

6. Actuate the flap control and simultaneously increase power to the predetermined setting (25" Hg) for the desired airspeed, and trim off the pressures necessary to hold constant altitude and heading. The attitude indicator now shows a bar-width nose-low in straight-and-level flight at 95 knots.

You will have developed a high level of proficiency in the basic skills involved in straight-and-level flight when you can consistently maintain constant altitude and heading with smooth pitch, bank, power, and trim control during these pronounced changes in trim.

Trim Technique

Proper **trim** technique is essential for smooth and precise aircraft control during all phases of flight. By relieving all control pressures, it is much easier to hold a given attitude constant, and you can devote more attention to other cockpit duties.

An aircraft is trimmed by applying control pressures to establish a desired attitude, then adjusting the trim so the aircraft will maintain that attitude when the flight controls are released. Trim the aircraft for coordinated flight by centering the ball of the turn-and-slip indicator. This is done by using rudder trim in the direction the ball is displaced from the center. Differential power control on multiengine aircraft is an additional factor affecting coordinated flight. Use balanced power or thrust, when possible, to aid in maintaining coordinated flight.

Changes in attitude, power, or configuration will require a trim adjustment, in most cases. Using trim alone to establish a change in aircraft attitude invariably leads to erratic aircraft control. Smooth and precise attitude changes are best attained by a combination of control pressures and trim adjustments. Therefore, when used correctly, trim adjustment is an aid to smooth aircraft control.

Common Errors in Straight-and-Level Flight

Pitch

Pitch errors usually result from the following faults:

1. Improper adjustment of the attitude indicator's miniature aircraft to the wings-level attitude. Following your initial level-off from a climb, check the attitude indicator and make any necessary adjustment in the miniature aircraft for level flight indication at normal cruise airspeed.
2. Insufficient cross-check and interpretation of pitch instruments. For example, the airspeed indication is low. Believing you are in a nose-high attitude, you react with forward pressure without noting that a low power setting is the cause of the airspeed discrepancy. Increase your cross-check speed to include all relevant instrument indications before you make a control response.
3. **Uncaging** the attitude indicator (if it has a caging feature) when the airplane is not in level flight. The altimeter and heading indicator must be stabilized with airspeed indication at normal cruise when you pull out the caging knob, if you expect the instrument to read straight-and-level at normal cruise airspeed.
4. Failure to interpret the attitude indicator in terms of the existing airspeed.
5. Late pitch corrections. Pilots commonly like to leave well enough alone. When the altimeter shows a 20-foot error, there is a reluctance to correct it, perhaps because of fear of overcontrolling. If overcontrolling is the error, the more you practice small corrections and find out the cause of overcontrolling, the closer you will be able to hold your altitude. If you tolerate a deviation, your errors will increase.
6. Chasing the vertical-speed indications. This tendency can be corrected by proper cross-check of other pitch instruments, as well as by increasing your understanding of the instrument characteristics.
7. Using excessive pitch corrections for the altimeter evaluation. Rushing a pitch correction by making a large pitch change usually aggravates the existing error and saves neither time nor effort.
8. Failure to maintain established pitch corrections. This is a common error associated with cross-check and trim errors. For example, having established a pitch change to correct an altitude error, you tend to slow down your cross-check, waiting for the airplane to stabilize in the new pitch attitude. To maintain the attitude, you must continue to cross-check and trim off the pressures you are holding.

Trim: Adjusting the aerodynamic forces on the control surfaces so that the aircraft maintains the set attitude without any control input.

Uncaging: Unlocking the gimbals of a gyroscopic instrument, making it susceptible to damage by abrupt flight maneuvers or rough handling.

9. Fixations during cross-check. After initiating a heading correction, for example, you become preoccupied with bank control and neglect to notice a pitch error. Likewise, during an airspeed change, unnecessary gazing at the power instrument is common. Bear in mind that a small error in power setting is of less consequence than large altitude and heading errors. The airplane will not decelerate any faster if you stare at the manifold pressure gauge than if you continue your cross-check.

Heading

Heading errors usually result from the following faults:

1. Failure to cross-check the heading indicator, especially during changes in power or pitch attitude.
2. Misinterpretation of changes in heading, with resulting corrections in the wrong direction.
3. Failure to note, and remember, a preselected heading.
4. Failure to observe the rate of heading change and its relation to bank attitude.
5. Overcontrolling in response to heading changes, especially during changes in power settings.
6. Anticipating heading changes with premature application of rudder control.
7. Failure to correct small heading deviations. Unless zero error in heading is your goal, you will find yourself tolerating larger and larger deviations. Correction of a 1° error takes a lot less time and concentration than correction of a 20° error.
8. Correcting with improper bank attitude. If you correct a 10° heading error with a 20° bank correction, you can roll past the desired heading before you have the bank established, requiring another correction in the opposite direction. Do not multiply existing errors with errors in corrective technique.
9. Failure to note the cause of a previous heading error and thus repeating the same error. For example, your airplane is out of trim, with a left wing low tendency. You repeatedly correct for a slight left turn, yet do nothing about trim.
10. Failure to set the heading indicator properly, or failure to uncage it.

Power

Power errors usually result from the following faults:

1. Failure to know the power settings and pitch attitudes appropriate to various airspeeds and airplane configurations.
2. Abrupt use of throttle.
3. Failure to lead the airspeed when making power changes. For example, during an airspeed reduction in level flight, especially with gear and flaps extended, adjust the throttle to maintain the slower speed before the airspeed reaches the desired speed. Otherwise, the airplane will decelerate to a speed lower than that desired, resulting in further power adjustments. How much you lead the airspeed depends upon how fast the airplane responds to power changes.
4. Fixation on airspeed or manifold pressure instruments during airspeed changes, resulting in erratic control of both airspeed and power.

Trim

Trim errors usually result from the following faults:

1. Improper adjustment of seat or rudder pedals for comfortable position of legs and feet. Tension in the ankles makes it difficult to relax rudder pressures.
2. Confusion as to the operation of trim devices, which differ among various airplane types. Some trim wheels are aligned appropriately with the airplane's axes; others are not. Some rotate in a direction contrary to what you expect.

3. Faulty sequence in trim technique. Trim should be used, not as a substitute for control with the wheel (stick) and rudders, but to relieve pressures already held to stabilize attitude. As you gain proficiency, you become familiar with trim settings, just as you do with power settings. With little conscious effort, you trim off pressures continually as they occur.

4. Excessive trim control. This induces control pressures that must be held until you retrim properly. Use trim frequently and in small amounts.

5. Failure to understand the cause of trim changes. If you do not understand the basic aerodynamics related to the basic instrument skills, you will continually lag behind the airplane.

Straight Climbs and Descents

Climbs

For a given power setting and load condition, there is only one attitude that will give the most efficient rate of climb. The airspeed and the climb power setting that will determine this climb attitude are given in the performance data found in your POH/AFM. Details of the technique for entering a climb vary according to airspeed on entry and the type of climb (constant airspeed or constant rate) desired. (Heading and trim control are maintained as discussed under straight-and-level flight.)

Entry

To enter a constant-airspeed climb from cruising airspeed, raise the miniature aircraft to the approximate nose-high indication for the predetermined climb speed. The attitude will vary according to the type of airplane you are flying. Apply light back-elevator pressure to initiate and maintain the climb attitude. The pressures will vary as the airplane decelerates. Power may be advanced to the climb power setting simultaneously with the pitch change, or after the pitch change is established and the airspeed approaches climb speed. If the transition from level flight to climb is smooth, the vertical speed indicator will show an immediate trend upward, continue to move slowly, then stop at a rate appropriate to the stabilized airspeed and attitude. (Primary and supporting instruments for the climb entry are shown in figure 5-25.)

Figure 5-25. *Climb entry for constant-airspeed climb.*

Figure 5-26. *Stabilized climb at constant airspeed.*

Once the airplane stabilizes at a constant airspeed and attitude, the airspeed indicator is primary for pitch and the heading indicator remains primary for bank. [Figure 5-26] You will monitor the tachometer or manifold pressure gauge as the primary power instrument to ensure the proper climb power setting is being maintained. If the climb attitude is correct for the power setting selected, the airspeed will stabilize at the desired speed. If the airspeed is low or high, make an appropriate small pitch correction.

To enter a constant-airspeed climb, first complete the airspeed reduction from cruise airspeed to climb speed in straight-and-level flight. The climb entry is then identical to entry from cruising airspeed, except that power must be increased simultaneously to the climb setting as the pitch attitude is increased. Climb entries on partial panel are more easily and accurately controlled if you enter the maneuver from climbing speed.

The technique for entering a constant-rate climb is very similar to that used for entry to a constant-airspeed climb from climb airspeed. As the power is increased to the approximate setting for the desired rate, simultaneously raise the miniature aircraft to the climbing attitude for the desired airspeed and rate of climb. As the power is increased, the airspeed indicator is primary for pitch control until the vertical speed approaches the desired value. As the vertical-speed needle stabilizes, it becomes primary for pitch control and the airspeed indicator becomes primary for power control. [Figure 5-27]

Pitch and power corrections must be promptly and closely coordinated. For example, if the vertical speed is correct, but the airspeed is low, add power. As the power is increased, the miniature aircraft must be lowered slightly to maintain constant vertical speed. If the vertical speed is high and the airspeed is low, lower the miniature aircraft slightly and note the increase in airspeed to determine whether or not a power change is also necessary. [Figure 5-28] Familiarity with the approximate power settings helps to keep your pitch and power corrections at a minimum.

Figure 5-27. *Stabilized climb at constant rate.*

Figure 5-28. *Airspeed low and vertical speed high—reduce pitch.*

Leveling Off

To level-off from a climb and maintain an altitude, it is necessary to start the level-off before reaching the desired altitude. The amount of lead varies with rate of climb and pilot technique. If your airplane is climbing at 1,000 fpm, it will continue to climb at a decreasing rate throughout the transition to level flight. An effective practice is to lead the altitude by 10 percent of the vertical speed shown (500 fpm/50-foot lead, 1,000 fpm/100-foot lead).

To level-off at cruising airspeed, apply smooth, steady forward-elevator pressure toward level-flight attitude for the speed desired. As the attitude indicator shows the pitch change, the vertical-speed needle will move slowly toward zero, the altimeter needle will move more slowly, and the airspeed will show acceleration. [Figure 5-29] Once the altimeter, attitude indicator, and vertical speed indicator show level flight, constant changes in pitch and torque control will have to be made as the airspeed increases. As the airspeed approaches cruising speed, reduce power to the cruise setting. The amount of lead depends upon the rate of acceleration of your airplane.

To level-off at climbing airspeed, lower the nose to the pitch attitude appropriate to that airspeed in level flight. Power is simultaneously reduced to the setting for that airspeed as the pitch attitude is lowered. If your power reduction is at a rate proportionate to the pitch change, the airspeed will remain constant.

Descents

A descent can be made at a variety of airspeeds and attitudes by reducing power, adding drag, and lowering the nose to a predetermined attitude. Sooner or later the airspeed will stabilize at a constant value. Meanwhile, the only flight instrument providing a positive attitude reference, by itself, is the attitude indicator. Without the attitude indicator (such as during a partial-panel descent) the airspeed indicator, the altimeter, and the vertical speed indicator will be showing varying rates of change until the airplane decelerates to a constant airspeed at a constant attitude. During the transition, changes in control pressure and trim, as well as cross-check and interpretation, must be very accurate if you expect to maintain positive control.

Figure 5-29. *Level-off at cruising speed.*

Entry

The following method for entering descents is effective either with or without an attitude indicator. First, reduce airspeed to your selected descent airspeed while maintaining straight-and-level flight, then make a further reduction in power (to a predetermined setting). As the power is adjusted, simultaneously lower the nose to maintain constant airspeed, and trim off control pressures.

During a constant-airspeed descent, any deviation from the desired airspeed calls for a pitch adjustment. For a constant-rate descent, the entry is the same, but the vertical-speed indicator is primary for pitch control (after it stabilizes near the desired rate), and the airspeed indicator is primary for power control. Pitch and power must be closely coordinated when corrections are made, as they are in climbs. [Figure 5-30]

Leveling Off

The level-off from a descent must be started before you reach the desired altitude. The amount of lead depends upon the rate of descent and control technique. With too little lead, you will tend to overshoot the selected altitude unless your technique is rapid. Assuming a 500-fpm rate of descent, lead the altitude by 100–150 feet for a level-off at an airspeed higher than descending speed. At the lead point, add power to the appropriate level-flight cruise setting. [Figure 5-31] Since the nose will tend to rise as the airspeed increases, hold forward-elevator pressure to maintain the vertical speed at the descending rate until approximately 50 feet above the altitude, then smoothly adjust the pitch attitude to the level-flight attitude for the airspeed selected.

To level-off from a descent at descent airspeed, lead the desired altitude by approximately 50 feet, simultaneously adjusting the pitch attitude to level flight and adding power to a setting that will hold the airspeed constant. [Figure 5-32] Trim off the control pressures and continue with the normal straight-and-level flight cross-check.

Figure 5-30. *Constant airspeed descent, airspeed high—reduce power.*

Figure 5-31. *Level-off airspeed higher than descent airspeed.*

Figure 5-32. *Level-off at descent airspeed.*

Common Errors in Straight Climbs and Descents

Common errors result from the following faults:

1. Overcontrolling pitch on climb entry. Until you know the pitch attitudes related to specific power settings used in climbs and descents, you will tend to make larger than necessary pitch adjustments. One of the most difficult habits to acquire during instrument training is to restrain the impulse to disturb a flight attitude until you know what the result will be. Overcome your inclination to make a large control movement for a pitch change, and learn to apply small control pressures smoothly, cross-checking rapidly for the results of the change, and continuing with the pressures as your instruments show the desired results at a rate you can interpret. Small pitch changes can be easily controlled, stopped, and corrected; large changes are more difficult to control.

2. Failure to vary the rate of cross-check during speed, power, or attitude changes or climb or descent entries.

3. Failure to maintain a new pitch attitude. For example, you raise the nose to the correct climb attitude, and as the airspeed decreases, you either overcontrol and further increase the pitch attitude, or allow the nose to lower. As control pressures change with airspeed changes, cross-check must be increased and pressures readjusted.

4. Failure to trim off pressures. Unless you trim, you will have difficulty determining whether control pressure changes are induced by aerodynamic changes or by your own movements.

5. Failure to learn and use proper power settings.

6. Failure to cross-check both airspeed and vertical speed before making pitch or power adjustments.

7. Improper pitch and power coordination on slow-speed level-offs, due to slow cross-check of airspeed and altimeter indications.

8. Failure to cross-check the vertical speed indicator against the other pitch control instruments, resulting in chasing the vertical speed.

9. Failure to note the rate of climb or descent to determine the lead for level-offs, resulting in overshooting or undershooting the desired altitude.

10. Ballooning (allowing the nose to pitch up) on level-offs from descents, resulting from failure to maintain descending attitude with forward-elevator pressure as power is increased to the level flight cruise setting.

11. Failure to recognize the approaching straight-and-level flight indications as you level-off. Until you have positively established straight-and-level flight, maintain an accelerated cross-check.

Turns

Standard-Rate Turns

To enter a standard-rate level turn, apply coordinated aileron and rudder pressures in the desired direction of turn. Pilots commonly roll into turns at a much too rapid rate. During initial training in turns, base your control pressures on your rate of cross-check and interpretation. There is nothing to be gained by maneuvering an airplane faster than your capacity to keep up with the changes in instrument indications.

On the roll-in, use the attitude indicator to establish the approximate angle of bank, then check the turn coordinator's miniature aircraft for a standard-rate turn indication. Maintain the bank for this rate of turn, using the turn coordinator's miniature aircraft as the primary bank reference and the attitude indicator as the supporting bank instrument. [Figure 5-33] Note the exact angle of bank shown on the banking scale of the attitude indicator when the turn coordinator indicates a standard-rate turn.

During the roll-in, check the altimeter, vertical speed indicator, and attitude indicator for the necessary pitch adjustments as the vertical lift component decreases with an increase in bank. If constant airspeed is to be maintained, the airspeed indicator becomes primary for power, and the throttle must be adjusted as drag increases. As the bank is established, trim off the pressures applied during pitch and power changes.

Figure 5-33. *Standard-rate turn, constant airspeed.*

To recover to straight-and-level flight, apply coordinated aileron and rudder pressures opposite the direction of turn. If you strive for the same rate of roll-out you used to roll into the turn, you will encounter fewer problems in estimating the lead necessary for roll-out on exact headings, especially on partial-panel maneuvers. As you initiate the turn recovery, the attitude indicator becomes the primary bank instrument. When the airplane is approximately level, the heading indicator is the primary bank instrument as in straight-and-level flight. Pitch, power, and trim adjustments are made as changes in vertical lift component and airspeed occur. The ball should be checked throughout the turn, especially if control pressures are held rather than trimmed off.

Some airplanes are very stable during turns, and slight trim adjustments permit hands-off flight while the airplane remains in the established attitude. Other airplanes require constant, rapid cross-check and control during turns to correct overbanking tendencies. Due to the interrelationship of pitch, bank, and airspeed deviations during turns, your cross-check must be fast in order to prevent an accumulation of errors.

Turns to Predetermined Headings

As long as an airplane is in a coordinated bank, it continues to turn. Thus, the roll-out to a desired heading must be started before the heading is reached. The amount of lead varies with the relationship between the rate of turn, angle of bank, and rate of recovery. For small heading changes, use a bank angle that does not exceed the number of degrees to be turned. Lead the desired heading by one-half the number of degrees of bank used. For example, if you maintain a 10° bank during a change in heading, start the roll-out 5° before you reach the desired heading. For larger changes in heading, the amount of lead will vary since the angle of bank for a standard-rate turn varies with the true airspeed.

Practice with a lead of one-half the angle of bank until you have determined the precise lead suitable to your technique. If your rates of roll-in and roll-out are consistent, you can readily determine the precise amount of lead suitable to your particular roll-out technique by noting the amount that you consistently undershoot or overshoot the headings.

Figure 5-34. *Turn coordinator calibration.*

Timed Turns

A timed turn is a turn in which the clock and the turn coordinator are used to change heading a definite number of degrees in a given time. For example, in a standard-rate turn (3° per second), an airplane turns 45° in 15 seconds; in a half-standard-rate turn, the airplane turns 45° in 30 seconds.

Prior to performing timed turns, the turn coordinator should be **calibrated** to determine the accuracy of its indications. [Figure 5-34] Establish a standard-rate turn as indicated by the turn coordinator, and as the sweep-second hand of the clock passes a cardinal point (12, 3, 6, 9), check the heading on the heading indicator. While holding the indicated rate of turn constant, note the indicated heading changes at 10-second intervals. If the airplane turns more or less than 30° in that interval, a larger or smaller deflection of the miniature aircraft of the turn coordinator is necessary to produce a standard-rate turn. When you have calibrated the turn coordinator during turns in each direction, note the corrected deflections, if any, and apply them during all timed turns.

The same cross-check and control technique is used in making timed turns that you use to execute turns to predetermined headings, except that you substitute the clock for the heading indicator. The miniature aircraft of the turn coordinator is primary for bank control, the altimeter is primary for pitch control, and the airspeed indicator is primary for power control. Start the roll-in when the clock's second hand passes a cardinal point, hold the turn at the calibrated standard rate indication (or half-standard rate for small heading changes), and begin the roll-out when the computed number of seconds has elapsed. If the rates of roll-in and roll-out are the same, the time taken during entry and recovery does not need to be considered in the time computation.

If you practice timed turns with a full instrument panel, check the heading indicator for the accuracy of your turns. If you execute the turns without the gyro heading indicator, use the magnetic compass at the completion of the turn to check turn accuracy, taking compass deviation errors into consideration.

Calibrated: The instrument indication was compared with a standard value to determine the accuracy of the instrument.

Compass Turns

In most small airplanes, the magnetic compass is the only direction-indicating instrument independent of other airplane instruments and power sources. Because of its operating characteristics, called compass errors, pilots are prone to use it only as a reference for setting the heading indicator, but a knowledge of magnetic compass characteristics will enable you to use the instrument to turn your airplane to correct headings and maintain them.

Bear in mind the following points when making turns to magnetic compass headings or when using the magnetic compass as a reference for setting the heading indicator:

1. If you are on a northerly heading and you start a turn to the east or west, the compass indication lags, or shows a turn in the opposite direction.

2. If you are on a southerly heading and you start a turn toward the east or west, the compass indication precedes the turn, showing a greater amount of turn than is actually occurring.

3. When you are on an east or west heading, the compass indicates correctly as you start a turn in either direction.

4. If you are on an easterly or westerly heading, acceleration results in a northerly turn indication; deceleration results in a southerly turn indication.

5. If you maintain a north or south heading, no error results from diving, climbing, or changing airspeed.

With an angle of bank between 15° and 18°, the amount of lead or lag to be used when turning to northerly or southerly headings varies with, and is approximately equal to, the latitude of the locality over which the turn is being made. When turning to a heading of north, the lead for roll-out must include the number of degrees of your latitude, plus the lead you normally use in recovery from turns. During a turn to a south heading, maintain the turn until the compass passes south the number of degrees of your latitude, minus your normal roll-out lead. [Figure 5-35]

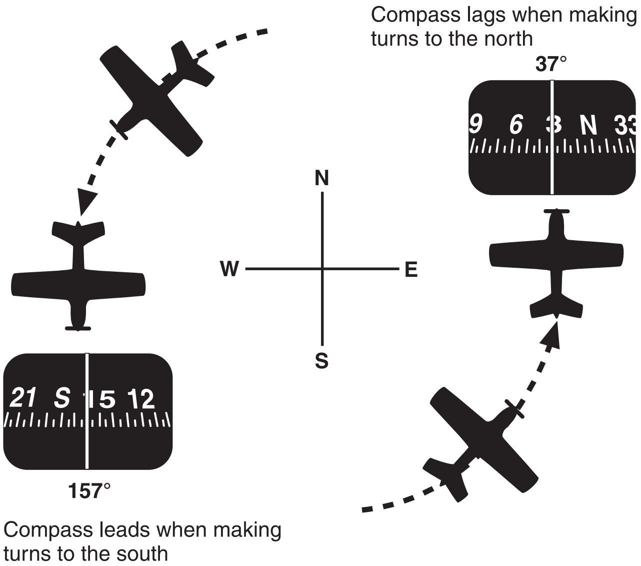


Figure 5-35. *Northerly and southerly turn error.*

For example, when turning from an easterly direction to north, where the latitude is 30°, start the roll-out when the compass reads 37° (30° plus one-half the 15° angle of bank, or whatever amount is appropriate for your rate of roll-out). When turning from an easterly direction to south, start the roll-out when the magnetic compass reads 203° (180° plus 30° minus one-half the angle of bank). When making similar turns from a westerly direction, the appropriate points at which to begin your roll-out would be 323° for a turn to north, and 157° for a turn to south.

When turning to a heading of east or west from a northerly direction, start the roll-out approximately 10° to 12° before the east or west indication is reached. When turning to an east or west heading from a southerly direction, start the roll-out approximately 5° before the east or west indication is reached. When turning to other headings, the lead or lag must be interpolated.

Abrupt changes in attitude or airspeed and the resulting erratic movements of the compass card make accurate interpretations of the instrument very difficult. Proficiency in compass turns depends on knowledge of the compass characteristics, smooth control technique, and accurate bank-and-pitch control.

Figure 5-36. *Steep left turn.*

Steep Turns

For purposes of instrument flight training in conventional airplanes, any turn greater than a standard rate may be considered steep. [Figure 5-36] The exact angle of bank at which a normal turn becomes steep is unimportant. What is important is that you learn to control the airplane with bank attitudes in excess of those you normally use on instruments. Practice in **steep turns** will not only increase your proficiency in the basic instrument flying skills, but also enable you to react smoothly, quickly, and confidently to unexpected abnormal flight attitudes under instrument flight conditions.

Pronounced changes occur in the effects of aerodynamic forces on aircraft control at progressively steepening bank attitudes. Skill in cross-check, interpretation, and control is increasingly necessary in proportion to the amount of these changes, though the techniques for entering, maintaining, and recovering from the turn are the same in principle for steep turns as for shallower turns.

Enter a steep turn exactly as you do a shallower turn, but prepare to cross-check rapidly as the turn steepens. Because of the greatly reduced vertical lift component, pitch control is usually the most difficult aspect of this maneuver. Unless immediately noted and corrected with a pitch increase, the loss of vertical lift results in rapid movement of the altimeter, vertical speed, and airspeed needles. The faster the rate of bank change, the more suddenly the lift changes occur. If your cross-check is fast enough to note the immediate need for pitch changes, smooth, steady back-elevator pressure will maintain constant altitude. However, if you overbank to excessively steep angles without adjusting pitch as the bank changes occur, pitch corrections require increasingly stronger

Steep turns: In instrument flight, anything greater than standard rate; in visual flight, anything greater than a 45° bank.

elevator pressure. The loss of vertical lift and increase in wing loading finally reach a point where further application of back-elevator pressure tightens the turn without raising the nose.

How do you recognize overbanking and a low pitch attitude? What should you do to correct it? If you observe a rapid downward movement of the altimeter needle or vertical-speed needle, together with an increase in airspeed, despite your application of back-elevator pressure, you are in a diving spiral. [Figure 5-37] Immediately shallow the bank with smooth and coordinated aileron and rudder pressures, hold or slightly relax elevator pressure, and increase your cross-check of the attitude indicator, altimeter, and vertical speed indicator. Reduce power if the airspeed increase is rapid. When the vertical speed trends upward, the altimeter needle will move slower as the vertical lift increases. When you note that the elevator is effective in raising the nose, hold the bank attitude shown on the attitude indicator and adjust elevator control pressures smoothly for the nose-high attitude appropriate to the bank maintained. If your pitch control is consistently late on your entries to steep turns, roll-out immediately to straight-and-level flight and analyze your errors. Practice shallower turns until you can keep up with the attitude changes and control responses required, then steepen the banks as you develop quicker and more accurate control technique.

The power necessary to maintain constant airspeed increases as the bank and drag increase. With practice, you quickly learn the power settings appropriate to specific bank attitudes, and can make adjustments without undue attention to airspeed and power instruments. During training in steep turns, as in any other maneuver, attend to first things first. If you keep the pitch attitude relatively constant, you have more time to cross-check, interpret, and control for accurate airspeed and bank control.

During recovery from steep turns to straight-and-level flight, elevator and power control must be coordinated with bank control in proportion to the changes in aerodynamic forces. Back-elevator pressures must be released and power decreased. The common errors associated with steep turns are the same as those discussed later in this section; however, remember, errors are more exaggerated, more difficult to correct, and more difficult to analyze unless your rates of entry and recovery are consistent with your level of proficiency in the three basic instrument flying skills.

Figure 5-37. *Diving spiral.*

Climbing and Descending Turns

To execute climbing and descending turns, combine the technique used in straight climbs and descents with the various turn techniques. The aerodynamic factors affecting lift and power control must be considered in determining power settings, and the rate of cross-check and interpretation must be increased to enable you to control bank as well as pitch changes.

Change of Airspeed in Turns

Changing airspeed in turns is an effective maneuver for increasing your proficiency in all three basic instrument skills. Since the maneuver involves simultaneous changes in all components of control, proper execution requires rapid cross-check and interpretation as well as smooth control. Proficiency in the maneuver will also contribute to your confidence in the instruments during attitude and power changes involved in more complex maneuvers. Pitch and power control techniques are the same as those used during changes in airspeed in straight-and-level flight.

The angle of bank necessary for a given rate of turn is proportional to the true airspeed. Since the turns are executed at a standard rate, the angle of bank must be varied in direct proportion to the airspeed change in order to maintain a constant rate of turn. During a reduction of airspeed, you must decrease the angle of bank and increase the pitch attitude to maintain altitude and a standard-rate turn.

The altimeter and turn coordinator indications should remain constant throughout the turn. The altimeter is primary for pitch control and the miniature aircraft of the turn coordinator is primary for bank control. The manifold pressure gauge (or tachometer) is primary for power control while the airspeed is changing. As the airspeed approaches the new indication, the airspeed indicator becomes primary for power control.

Two methods of changing airspeed in turns may be used. In the first method, airspeed is changed after the turn is established [Figure 5-38]; in the second method, the airspeed change is initiated simultaneously with the turn entry. The first method is easier, but regardless of the method used, the rate of cross-check must be increased as you reduce power. As the airplane decelerates, check the altimeter and vertical speed indicator for needed pitch changes and the bank instruments for needed bank changes. If the miniature aircraft of the turn coordinator shows a deviation from the desired deflection, change the bank. Adjust pitch attitude to maintain altitude. When approaching the desired airspeed, it becomes primary for power control and the manifold pressure gauge (or tachometer) is adjusted to maintain the desired airspeed. Trim is important throughout the maneuver to relieve control pressures.

Figure 5-38. *Change of airspeed in turn.*

Until your control technique is very smooth, frequent cross-check of the attitude indicator is essential to keep from overcontrolling and to provide approximate bank angles appropriate to the changing airspeeds.

Common Errors in Turns

Pitch

Pitch errors result from the following faults:

1. Preoccupation with bank control during turn entry and recovery. If it takes 5 seconds to roll into a turn, check the pitch instruments as you initiate bank pressures. If your bank control pressure and rate of bank change are consistent, you will soon develop a sense of timing that tells you how long an attitude change will take. During the interval, you check pitch, power, and trim—as well as bank—controlling the total attitude instead of one factor at a time.

2. Failure to understand or remember the need for changing the pitch attitude as the vertical lift component changes, resulting in consistent loss of altitude during entries.

3. Changing the pitch attitude before it is necessary. This fault is very likely if your cross-check is slow and your rate of entry too rapid. The error occurs during the turn entry due to a mechanical and premature application of back-elevator control pressure.

4. Overcontrolling the pitch changes. This fault commonly occurs with the previous error.

5. Failure to properly adjust the pitch attitude as the vertical lift component increases during the roll-out, resulting in consistent gain in altitude on recovery to headings.

6. Failure to trim during turn entry and following turn recovery (if turn is prolonged).

7. Failure to maintain straight-and-level cross-check after roll-out. This error commonly follows a perfectly executed turn.

8. Erratic rates of bank change on entry and recovery, resulting from failure to cross-check the pitch instruments with a consistent technique appropriate to the changes in lift.

Bank

Bank and heading errors result from the following faults:

1. Overcontrolling, resulting in overbanking upon turn entry, overshooting and undershooting headings, as well as aggravated pitch, airspeed, and trim errors.

2. Fixation on a single bank instrument. On a 90° change of heading, for example, leave the heading indicator out of your cross-check for approximately 20 seconds after establishing a standard-rate turn, since at 3° per second you will not approach the lead point until that time has elapsed. Make your cross-check selective; check what needs to be checked at the appropriate time.

3. Failure to check for precession of the horizon bar following recovery from a turn. If the heading indicator shows a change in heading when the attitude indicator shows level flight, the airplane is turning. If the ball is centered, the attitude gyro has precessed; if the ball is not centered, the airplane may be in a slipping or skidding turn. Center the ball with rudder pressure, check the attitude indicator and heading indicator, stop the heading change if it continues, and retrim.

4. Failure to use the proper degree of bank for the amount of heading change desired. Rolling into a 20° bank for a heading change of 10° will normally overshoot the heading. Use the bank attitude appropriate to the amount of heading change desired.

5. Failure to remember the heading you are turning to. This fault is likely when you rush the maneuver.

6. Turning in the wrong direction, due either to misreading or misinterpreting the heading indicator, or to confusion as to the location of points on the compass. Turn in the shortest direction to reach a given heading, unless you

have a specific reason to turn the long way around. Study the compass rose until you can visualize at least the positions of the eight major points around the azimuth. A number of methods can be used to make quick computations for heading changes. For example, to turn from a heading of 305° to a heading of 110°, do you turn right or left for the shortest way around? Subtracting 200 from 305 and adding 20, you get 125° as the reciprocal of 305°; therefore, execute the turn to the right. Likewise, to figure the reciprocal of a heading less than 180°, add 200 and subtract 20. If you can compute more quickly using multiples of 100s and 10s than by adding or subtracting 180° from the actual heading, the method suggested above may save you time and confusion.

7. Failure to check the ball of the turn coordinator when interpreting the instrument for bank information. If the roll rate is reduced to zero, the miniature aircraft of the turn coordinator indicates only direction and rate of turn. Unless the ball is centered, you cannot assume the turn is resulting from a banked attitude.

Power

Power and airspeed errors result from the following faults:

1. Failure to cross-check the airspeed indicator as you make pitch changes.

2. Erratic use of power control. This may be due to improper throttle friction control, inaccurate throttle settings, chasing the airspeed readings, abrupt or overcontrolled pitch-and-bank changes, or failure to recheck the airspeed to note the effect of a power adjustment.

3. Poor coordination of throttle control with pitch-and-bank changes, associated with slow cross-check or failure to understand the aerodynamic factors related to turns.

Trim

Trim errors result from the following faults:

1. Failure to recognize the need for a trim change may be due to slow cross-check and interpretation. For example, a turn entry at a rate too rapid for your cross-check leads to confusion in cross-check and interpretation, with resulting tension on the controls.

2. Failure to understand the relationship between trim and attitude/power changes.

3. Chasing the vertical-speed needle. Overcontrolling leads to tension and prevents you from sensing the pressures to be trimmed off.

4. Failure to trim following power changes.

Errors During Compass Turns

In addition to the faults discussed above, the following errors connected with compass turns should be noted:

1. Faulty understanding or computation of lead and lag.

2. Fixation on the compass during the roll-out. Until the airplane is in straight-and-level, unaccelerated flight, there is no point in reading the indicated heading. Accordingly, after you initiate the roll-out, cross-check for straight-and-level flight before checking the accuracy of your turn.

Approach to Stall

Practicing approach to stall recoveries in various airplane configurations should build confidence in your ability to control the airplane in unexpected situations. Approach to stall should be practiced from straight flight and from shallow banks. The objective is to practice recognition and recovery from the approach to a stall.

Prior to stall recovery practice, select a safe altitude above the terrain, an area free of conflicting air traffic, adequate weather, and the use of radar traffic advisory service should be among the items considered.

Approach to stalls are accomplished in the following configurations:

1. Takeoff configuration—should begin from level flight near liftoff speed. Power should be applied while simultaneously increasing the angle of attack to induce an indication of a stall.

2. Clean configuration—should begin from a reduced airspeed, such as pattern airspeed, in level flight. Power should be applied while simultaneously increasing the angle of attack to induce an indication of a stall.

3. Approach or landing configuration—should be initiated at the appropriate approach or landing airspeed. The angle of attack should be smoothly increased to induce an indication of a stall.

Recoveries should be prompt in response to a stall warning device or an aerodynamic indication, by smoothly reducing the angle of attack and applying maximum power, or as recommended by the POH/AFM. The recovery should be completed without an excessive loss of altitude, and on a predetermined heading, altitude, and airspeed.

Unusual Attitudes and Recoveries

An unusual attitude is an airplane attitude not normally required for instrument flight. Unusual attitudes may result from a number of conditions, such as turbulence, disorientation, instrument failure, confusion, preoccupation with cockpit duties, carelessness in cross-checking, errors in instrument interpretation, or lack of proficiency in aircraft control. Since unusual attitudes are not intentional maneuvers during instrument flight, except in training, they are often unexpected, and the reaction of an inexperienced or inadequately trained pilot to an unexpected abnormal flight attitude is usually instinctive rather than intelligent and deliberate. This individual reacts with abrupt muscular effort, which is purposeless and even hazardous in turbulent conditions, at excessive speeds, or at low altitudes. However, with practice, the techniques for rapid and safe recovery from unusual attitudes can be learned.

When an unusual attitude is noted on your cross-check, the immediate problem is not how the airplane got there, but what it is doing and how to get it back to straight-and-level flight as quickly as possible.

Recognizing Unusual Attitudes

As a general rule, any time you note an instrument rate of movement or indication other than those you associate with the basic instrument flight maneuvers already learned, assume an unusual attitude and increase the speed of cross-check to confirm the attitude, instrument error, or instrument malfunction.

Nose-high attitudes are shown by the rate and direction of movement of the altimeter needle, vertical-speed needle, and airspeed needle, as well as the immediately recognizable indication of the attitude indicator (except in extreme attitudes). [Figure 5-39] Nose-low attitudes are shown by the same instruments, but in the opposite direction. [Figure 5-40]

Figure 5-39. *Unusual attitude—nose high.*

Figure 5-40. *Unusual attitude—nose-low.*

Recovery From Unusual Attitudes

In moderate unusual attitudes, the pilot can normally reorient him/herself by establishing a level flight indication on the attitude indicator. However, the pilot should not depend on this instrument for the following reasons: If the attitude indicator is the spillable type, its upset limits may have been exceeded; it may have become inoperative due to mechanical malfunction; even if it is the nonspillable-type instrument and is operating properly, errors up to 5° of pitch-and-bank may result and its indications are very difficult to interpret in extreme attitudes. As soon as the unusual attitude is detected, the recommended recovery procedures stated in the POH/AFM should be initiated. If there are no recommended procedures stated in the POH/AFM, the recovery should be initiated by reference to the airspeed indicator, altimeter, vertical speed indicator, and turn coordinator.

Nose-High Attitudes

If the airspeed is decreasing, or below the desired airspeed, increase power (as necessary in proportion to the observed deceleration), apply forward-elevator pressure to lower the nose and prevent a stall, and correct the bank by applying coordinated aileron and rudder pressure to level the miniature aircraft and center the ball of the turn coordinator. The corrective control applications are made almost simultaneously, but in the sequence given above. A level pitch attitude is indicated by the reversal and stabilization of the airspeed indicator and altimeter needles. Straight coordinated flight is indicated by the level miniature aircraft and centered ball of the turn coordinator.

Nose-Low Attitudes

If the airspeed is increasing, or is above the desired airspeed, reduce power to prevent excessive airspeed and loss of altitude. Correct the bank attitude with coordinated aileron and rudder pressure to straight flight by referring to the turn coordinator. Raise the nose to level flight attitude by applying smooth back-elevator pressure. All components of control should be changed simultaneously for a smooth, proficient recovery. However, during initial training a positive, confident recovery should be made by the numbers, in the sequence given above. A very important point to remember is that the instinctive reaction to a nose-down attitude is to pull back on the elevator control.

After initial control has been applied, continue with a fast cross-check for possible overcontrolling, since the necessary initial control pressures may be large. As the rate of movement of altimeter and airspeed indicator needles decreases, the attitude is approaching level flight. When the needles stop and reverse direction, the aircraft is passing through level flight. As the indications of the airspeed indicator, altimeter, and turn coordinator stabilize, incorporate the attitude indicator into the cross-check.

The attitude indicator and turn coordinator should be checked to determine bank attitude, and then corrective aileron and rudder pressures should be applied. The ball should be centered. If it is not, skidding and slipping sensations can easily aggravate disorientation and retard recovery. If you enter the unusual attitude from an assigned altitude (either by your instructor or by air traffic control (ATC) if operating under instrument flight rules (IFR)), return to the original altitude after stabilizing in straight-and-level flight.

Common Errors in Unusual Attitudes

Common errors associated with unusual attitudes include the following faults:

1. Failure to keep the airplane properly trimmed. A cockpit interruption when you are holding pressures can easily lead to inadvertent entry into unusual attitudes.

2. Disorganized cockpit. Hunting for charts, logs, computers, etc., can seriously detract your attention from the instruments.

3. Slow cross-check and fixations. Your impulse is to stop and stare when you note an instrument discrepancy unless you have trained enough to develop the skill required for immediate recognition.

4. Attempting to recover by sensory sensations other than sight. The discussion of disorientation in Chapter 1 ("Human Factors") indicates the importance of trusting your instruments.

5. Failure to practice basic instrument skills once you have learned them. All of the errors noted in connection with basic instrument skills are aggravated during unusual attitude recoveries until the elementary skills have been mastered.

Instrument Takeoff

Your competency in **instrument takeoffs** will provide the proficiency and confidence necessary for use of flight instruments during departures under conditions of low visibility, rain, low ceilings, or disorientation at night. A sudden rapid transition from "visual" to "instrument" flight can result in serious disorientation and control problems.

Instrument takeoff techniques vary with different types of airplanes, but the method described below is applicable whether the airplane is single- or multiengine; tricycle-gear or conventional-gear.

Align the airplane with the centerline of the runway with the nosewheel or tailwheel straight. (Your instructor pilot may align the airplane if he/she has been taxiing while you perform the instrument check under a hood or visor.) Lock the tailwheel, if so equipped, and hold the brakes firmly to avoid creeping while you prepare for takeoff. Set the heading indicator with the nose index on the 5° mark nearest the published runway heading, so you can instantly detect slight changes in heading during the takeoff. Make certain that the instrument is uncaged (if it has a caging feature) by rotating the knob after uncaging and checking for constant heading indication. If you use an electric heading indicator with a rotatable needle, rotate the needle so that it points to the nose position, under the top index. Advance the throttle to an RPM that will provide partial rudder control. Release the brakes, advancing the power smoothly to takeoff setting.

During the takeoff roll, hold the heading constant on the heading indicator by using the rudder. In multiengine, propeller-driven airplanes, also use differential throttle to maintain direction. The use of brakes should be avoided,

Instrument takeoff: Using the instruments rather than outside visual cues to maintain runway heading and execute a safe takeoff.

except as a last resort, as it usually results in overcontrolling and extending the takeoff roll. Once you release the brakes, any deviation in heading must be corrected instantly.

As the airplane accelerates, cross-check both heading indicator and airspeed indicator rapidly. The attitude indicator may precess to a slight nose-up attitude. As flying speed is approached (approximately 15-25 knots below takeoff speed), smoothly apply elevator control for the desired takeoff attitude on the attitude indicator. This is approximately a 2-bar-width climb indication for most small airplanes.

Continue with a rapid cross-check of heading indicator and attitude indicator as the airplane leaves the ground. Do not pull it off; let it fly off while you hold the selected attitude constant. Maintain pitch-and-bank control by referencing the attitude indicator, and make coordinated corrections in heading when indicated on the heading indicator. Cross-check the altimeter and vertical speed indicator for a positive rate of climb (steady clockwise rotation of the altimeter needle at a rate that you can interpret with experience, and the vertical speed indicator showing a stable rate of climb appropriate to the airplane).

When the altimeter shows a safe altitude (approximately 100 feet), raise the landing gear and flaps, maintaining attitude by referencing the attitude indicator. Because of control pressure changes during gear and flap operation, overcontrolling is likely unless you note pitch indications accurately and quickly. Trim off control pressures necessary to hold the stable climb attitude. Check the altimeter, vertical speed indicator, and airspeed for a smooth acceleration to the predetermined climb speed (altimeter and airspeed increasing, vertical speed stable). At climb speed, reduce power to climb setting (unless full power is recommended for climb by your POH/AFM and trim).

Throughout the instrument takeoff, cross-check and interpretation must be rapid, and control positive and smooth. During liftoff, gear and flap retraction, and power reduction, the changing control reactions demand rapid cross-check, adjustment of control pressures, and accurate trim changes.

Common Errors in Instrument Takeoffs

Common errors during the instrument takeoff include the following:

1. Failure to perform an adequate cockpit check before the takeoff. Pilots have attempted instrument takeoffs with inoperative airspeed indicators (pitot tube obstructed), gyros caged, controls locked, and numerous other oversights due to haste or carelessness.

2. Improper alignment on the runway. This may result from improper brake application, allowing the airplane to creep after alignment, or from alignment with the nosewheel or tailwheel cocked. In any case, the result is a built-in directional control problem as the takeoff starts.

3. Improper application of power. Abrupt application of power complicates directional control. Add power with a smooth, uninterrupted motion.

4. Improper use of brakes. Incorrect seat or rudder pedal adjustment, with your feet in an uncomfortable position, frequently causes inadvertent application of brakes and excessive heading changes.

5. Overcontrolling rudder pedals. This fault may be caused by late recognition of heading changes, tension on the controls, misinterpretation of the heading indicator (and correcting in the wrong direction), failure to appreciate changing effectiveness of rudder control as the aircraft accelerates, and other factors. If heading changes are observed and corrected instantly with small movement of the rudder pedals, swerving tendencies can be reduced.

6. Failure to maintain attitude after becoming airborne. If you react to seat-of-the-pants sensations when the airplane lifts off, your pitch control is guesswork. You may either allow excessive pitch or apply excessive forward-elevator pressure, depending on your reaction to trim changes.

7. Inadequate cross-check. Fixations are likely during trim changes, attitude changes, gear and flap retractions, and power changes. Once you check an instrument or apply a control, continue the cross-check and note the effect of your control during the next cross-check sequence.

8. Inadequate interpretation of instruments. Failure to understand instrument indications immediately indicates that further study of the maneuver is necessary.

Basic Instrument Flight Patterns

After you have attained a reasonable degree of proficiency in basic maneuvers, you can apply your skills to the various combinations of individual maneuvers. The following practice **flight patterns** are directly applicable to operational instrument flying.

Racetrack Pattern

Steps:

1. Time 3 minutes straight-and-level flight from A to B. [Figure 5-41] During this interval, reduce airspeed to the holding speed appropriate for your aircraft.
2. Start 180° standard-rate turn at B. Roll-out at C on the reciprocal of your heading at A.
3. Time 1 minute straight-and-level flight from C to D.
4. Start 180° standard rate level turn at D, rolling-out on original heading.

Note: This pattern is an exercise combining use of the clock with basic maneuvers.

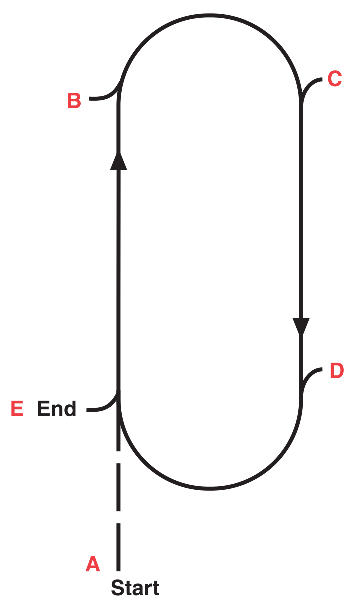


Figure 5-41. *Racetrack pattern (entire pattern in level flight).*

Flight patterns: Basic maneuvers, flown by sole reference to the instruments rather than outside visual cues, for the purpose of practicing basic attitude flying. The patterns simulate maneuvers encountered on instrument flights such as holding patterns, procedure turns, and approaches.

Standard Procedure Turn

Steps:

1. Start timing at A for 2 minutes from A to B. [Figure 5-42]
2. At B, turn 45° (standard rate). After roll-out, fly 1 minute to C.
3. At C, turn 180°.
4. At completion of turn, time 45 seconds from D to E.
5. Start turn at E for 45° change of heading to reciprocal of heading at beginning of maneuver.

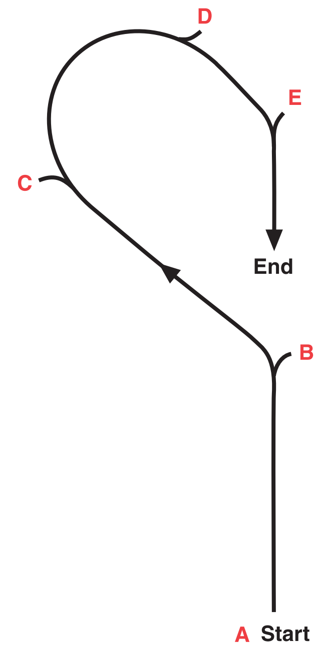


Figure 5-42. *Standard procedure turn (entire pattern in level flight).*

80/260 Procedure Turn

Steps:

1. Start timing at A for 2 minutes from A to B. [Figure 5-43]
2. At B, enter a left standard-rate turn for a heading change of 80°.
3. At the completion of the 80° turn at C, immediately turn right for a heading change of 260°, rolling-out on the reciprocal of the entry heading.

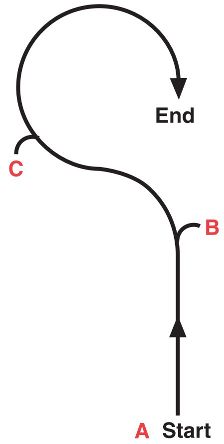


Figure 5-43. *80/260 procedure turn (entire pattern in level flight).*

Teardrop Pattern

Steps:

1. Start timing at A for 2 minutes from A to B. [Figure 5-44] Reduce airspeed to holding speed in this interval.
2. At B, enter standard-rate turn for 30° change of heading. Time 1 minute from B to C.
3. At C, enter standard-rate turn for a 210° change of heading, rolling-out on the reciprocal of the original entry heading.

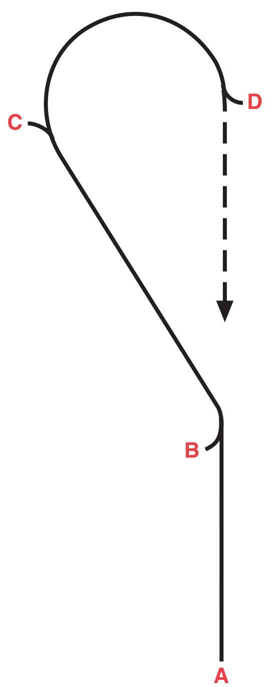


Figure 5-44. *Teardrop pattern (entire pattern in level flight).*

Circling Approaches Pattern

Pattern I

Steps:

1. At A, start timing for 2 minutes from A to B; reduce airspeed to approach speed. [Figure 5-45, I]
2. At B, make a standard-rate turn to the left for 45°.
3. At the completion of the turn, time for 45 seconds to C.
4. At C, turn to the original heading; fly 1 minute to D, lowering the landing gear and flaps.
5. At D, turn right 180°, rolling-out at E on the reciprocal of the entry heading.
6. At E, enter a 500 fpm rate descent. At the end of a 500-foot descent, enter a straight constant-airspeed climb, retracting gear and flaps.

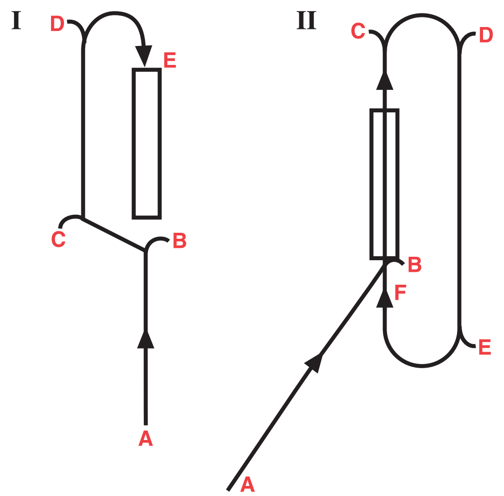


Figure 5-45. *Patterns applicable to circling approaches (runways are imaginary).*

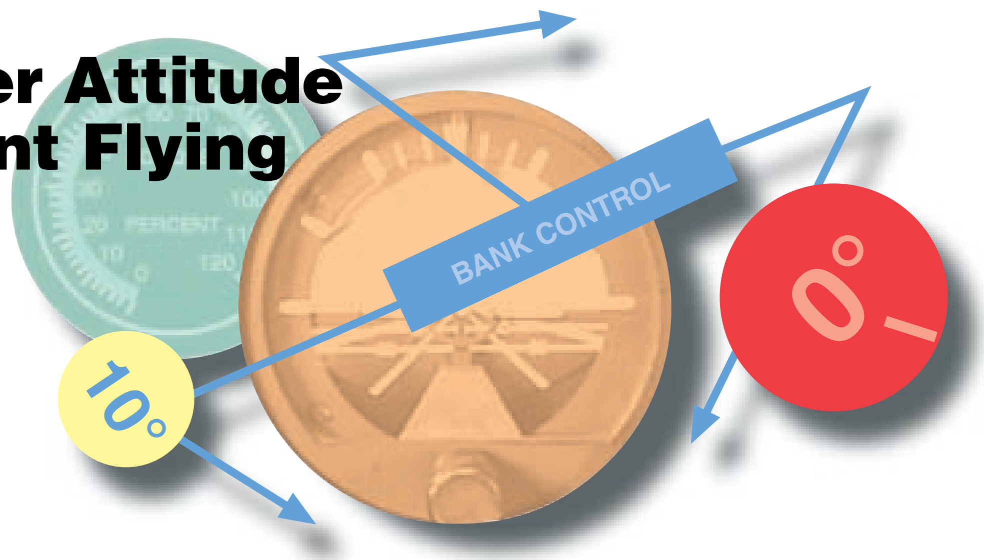
Pattern II

Steps:

1. At A, start timing for 2 minutes from A to B; reduce airspeed to approach speed. [Figure 5-45, II]
2. At B, make a standard-rate turn to the left for 45°.
3. At the completion of the turn, time for 1 minute to C.
4. At C, turn right for 180°; fly for 1-1/2 minutes to E, lowering the landing gear and flaps.
5. At E, turn right for 180°, rolling-out at F.
6. At F, enter a 500 fpm rate descent. At the end of a 500-foot descent, enter a straight constant-airspeed climb, retracting gear and flaps.

Chapter 6

Helicopter Attitude Instrument Flying



Introduction

Attitude instrument flying in helicopters is essentially visual flying with the flight instruments substituted for the various reference points on the helicopter and the natural horizon. Control changes, required to produce a given attitude by reference to instruments, are identical to those used in helicopter visual flight rules (VFR) flight, and your thought processes are the same. Basic instrument training is intended as a building block towards attaining an instrument rating.

Flight Instruments

When flying a helicopter with reference to the flight instruments, proper instrument interpretation is the basis for aircraft control. Your skill, in part, depends on your understanding of how a particular instrument or system functions, including its indications and limitations (*see* Chapter 3, "Flight Instruments"). With this knowledge, you can quickly determine what an instrument is telling you and translate that information into a control response.

Instrument Flight

To achieve smooth, positive control of the helicopter during instrument flight, you need to develop three fundamental skills. They are instrument cross-check, instrument interpretation, and aircraft control.

Attitude instrument flying: Controlling the aircraft by reference to the instruments rather than outside visual cues.

Instrument Cross-Check

Cross-checking, sometimes referred to as scanning, is the continuous and logical observation of instruments for attitude and performance information. In attitude instrument flying, an attitude is maintained by reference to the instruments, which produces the desired result in performance. Due to human error, instrument error, and helicopter performance differences in various atmospheric and loading conditions, it is difficult to establish an attitude and have performance remain constant for a long period of time. These variables make it necessary for you to constantly check the instruments and make appropriate changes in the helicopter's attitude. The actual technique may vary depending on what instruments are installed and where they are installed, as well as your experience and proficiency level. This discussion concentrates on the six basic flight instruments. [Figure 6-1]

At first, you may have a tendency to cross-check rapidly, looking directly at the instruments without knowing exactly what information you are seeking. However, with familiarity and practice, the instrument cross-check reveals definite trends during specific flight conditions. These trends help you control the helicopter as it makes a transition from one flight condition to another.

Figure 6-1. *In most situations, the cross-check pattern includes the attitude indicator between the cross-check of each of the other instruments. A typical cross-check might progress as follows: attitude indicator, altimeter, attitude indicator, vertical speed indicator, attitude indicator, heading indicator, attitude indicator, and so on.*

If you apply your full concentration to a single instrument, you will encounter a problem called **fixation**. This results from a natural human inclination to observe a specific instrument carefully and accurately, often to the exclusion of other instruments. Fixation on a single instrument usually results in poor control. For example, while performing a turn, you may have a tendency to watch only the turn-and-slip indicator instead of including other instruments in your cross-check. This fixation on the turn-and-slip indicator often leads to a loss of altitude through poor pitch-and-bank control. You should look at each instrument only long enough to understand the information it presents, then continue on to the next one. Similarly, you may find yourself placing too much "emphasis" on a single instrument, instead of relying on a combination of instruments necessary for helicopter performance information. This differs from fixation in that you are using other instruments, but are giving too much attention to a particular one.

During performance of a maneuver, you may sometimes fail to anticipate significant instrument indications following attitude changes. For example, during level-off from a climb or descent, you may concentrate on pitch control, while forgetting about heading or roll information. This error, called "omission," results in erratic control of heading and bank.

In spite of these common errors, most pilots can adapt well to flight by instrument reference after instruction and practice. You may find that you can control the helicopter more easily and precisely by instruments.

Fixation: Staring at a single instrument, thereby interrupting the cross-check process.

Instrument Interpretation

The flight instruments together give a picture of what is going on. No one instrument is more important than the next; however, during certain maneuvers or conditions, those instruments that provide the most pertinent and useful information are termed primary instruments. Those which back up and supplement the primary instruments are termed supporting instruments. For example, since the attitude indicator is the only instrument that provides instant and direct aircraft attitude information, it should be considered primary during any change in pitch or bank attitude. After the new attitude is established, other instruments become primary, and the attitude indicator usually becomes the supporting instrument.

Aircraft Control

Controlling the helicopter is the result of accurately interpreting the flight instruments and translating these readings into correct control responses. Aircraft control involves adjustment to pitch, bank, power, and trim in order to achieve a desired flight path.

Pitch attitude control is controlling the movement of the helicopter about its lateral axis. After interpreting the helicopter's pitch attitude by reference to the pitch instruments (attitude indicator, altimeter, airspeed indicator, and vertical speed indicator), cyclic control adjustments are made to affect the desired pitch attitude. In this chapter, the pitch attitudes depicted are approximate and will vary with different helicopters.

Bank attitude control is controlling the angle made by the lateral tilt of the rotor and the natural horizon, or, the movement of the helicopter about its longitudinal axis. After interpreting the helicopter's bank instruments (attitude indicator, heading indicator, and turn indicator), cyclic control adjustments are made to attain the desired bank attitude.

Power control is the application of collective pitch with corresponding throttle control, where applicable. In straight-and-level flight, changes of collective pitch are made to correct for altitude deviations if the error is more than 100 feet, or the airspeed is off by more than 10 knots. If the error is less than that amount, use a slight cyclic climb or descent.

In order to fly a helicopter by reference to the instruments, you should know the approximate power settings required for your particular helicopter in various load configurations and flight conditions.

Trim, in helicopters, refers to the use of the cyclic centering button, if the helicopter is so equipped, to relieve all possible cyclic pressures. Trim also refers to the use of pedal adjustment to center the ball of the turn indicator. Pedal trim is required during all power changes.

The proper adjustment of collective pitch and cyclic friction helps you relax during instrument flight. Friction should be adjusted to minimize **overcontrolling** and to prevent creeping, but not applied to such a degree that control movement is limited. In addition, many helicopters equipped for instrument flight contain stability augmentation systems or an autopilot to help relieve pilot workload.

Straight-and-Level Flight

Straight-and-level unaccelerated flight consists of maintaining the desired altitude, heading, airspeed, and pedal trim.

Pitch Control

The pitch attitude of a helicopter is the angular relation of its longitudinal axis and the natural horizon. If available, the attitude indicator is used to establish the desired pitch attitude. In level flight, pitch attitude varies with airspeed and center of gravity. At a constant altitude and a stabilized airspeed, the pitch attitude is approximately level. [Figure 6-2]

Attitude Indicator

The attitude indicator gives a **direct indication** of the pitch attitude of the helicopter. In visual flight, you attain the desired pitch attitude by using the cyclic to raise and lower the nose of the helicopter in relation to the natural horizon. During instrument flight, you follow exactly the same procedure in raising or lowering the miniature aircraft in relation to the horizon bar.

You may note some delay between control application and resultant instrument change. This is the normal control lag in the helicopter and should not be confused with instrument lag. The attitude indicator may show small misrepresentations of pitch attitude during maneuvers involving acceleration,

Overcontrolling: Using more movement in the cyclic or collective than necessary to achieve the desired pitch-and-bank condition.

Direct indication: The true and instantaneous reflection of aircraft pitch-and-bank attitude by the miniature aircraft, relative to the horizon bar of the attitude indicator.

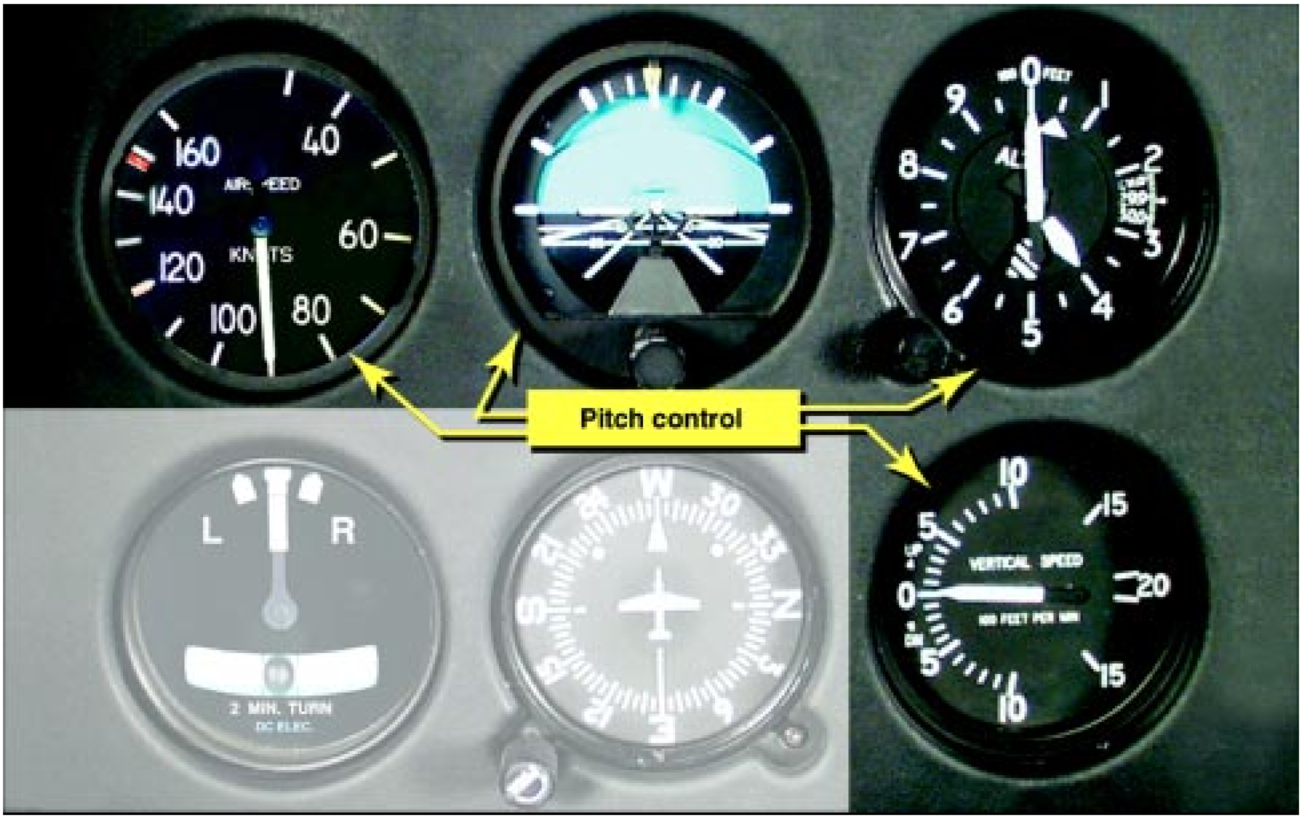


Figure 6-2. *The flight instruments for pitch control are the airspeed indicator, attitude indicator, altimeter, and vertical speed indicator.*

deceleration, or turns. This precession error can be detected quickly by cross-checking the other pitch instruments.

If the miniature aircraft is properly adjusted on the ground, it may not require readjustment in flight. If the miniature aircraft is not on the horizon bar after level-off at normal cruising airspeed, adjust it as necessary while maintaining level flight with the other pitch instruments. Once the miniature aircraft has been adjusted in level flight at normal cruising airspeed, leave it unchanged so it will give an accurate picture of pitch attitude at all times.

When making initial pitch attitude corrections to maintain altitude, the changes of attitude should be small and smoothly applied. The initial movement of the horizon bar should not exceed one bar width high or low. [Figure 6-3] If a further change is required, an additional correction of one-half bar normally corrects any deviation from the desired altitude. This one-and-one-half bar correction is normally the maximum pitch attitude correction from level flight attitude. After you have made the correction, cross-check the other pitch instruments to determine whether the pitch attitude

Figure 6-3. *The initial pitch correction at normal cruise is one bar width.*

change is sufficient. If more correction is needed to return to altitude, or if the airspeed varies more than 10 knots from that desired, adjust the power.

Altimeter

The altimeter gives an **indirect indication** of the pitch attitude of the helicopter in straight-and-level flight. Since the altitude should remain constant in level flight, deviation from the desired altitude shows a need for a change in pitch attitude, and if necessary, power. When losing altitude, raise the pitch attitude and, if necessary, add power. When gaining altitude, lower the pitch attitude and, if necessary, reduce power.

The rate at which the altimeter moves helps in determining pitch attitude. A very slow movement of the altimeter indicates a small deviation from the desired pitch attitude, while a fast movement of the altimeter indicates a large deviation from the desired pitch attitude. Make any corrective action promptly, with small control changes. Also, remember that movement of the altimeter should always be corrected by two distinct changes. The first is a change of attitude to stop the altimeter; and the second, a change of attitude to return smoothly to the desired altitude. If the altitude and airspeed are more than 100 feet and 10 knots low, respectively, apply power along with an increase of pitch attitude. If the altitude and airspeed are high by more than 100 feet and 10 knots, reduce power and lower the pitch attitude.

There is a small lag in the movement of the altimeter; however, for all practical purposes, consider that the altimeter gives an immediate indication of a change, or a need for change in pitch attitude.

Since the altimeter provides the most pertinent information regarding pitch in level flight, it is considered primary for pitch.

Vertical Speed Indicator

The vertical speed indicator (VSI) gives an indirect indication of the pitch attitude of the helicopter and should be used in conjunction with the other pitch instruments to attain a high degree of accuracy and precision. The instrument indicates zero when in level flight. Any movement of the needle from the zero position shows a need for an immediate change in pitch attitude to return it to zero. Always use the vertical speed indicator in conjunction with the altimeter in level flight. If a movement of the vertical speed indicator is detected, immediately use the proper corrective measures to return it to zero. If the correction is made promptly, there is usually little or no change in altitude. If you do not zero the needle of the vertical speed indicator immediately, the results will show on the altimeter as a gain or loss of altitude.

The initial movement of the vertical speed needle is instantaneous and indicates the trend of the vertical movement of the helicopter. A period of time is necessary for the vertical speed indicator to reach its maximum point of deflection after a correction has been made. This time element is commonly referred to as **lag**. The lag is directly proportional to the speed and magnitude of the pitch change. If you employ smooth control techniques and make small adjustments in pitch attitude, lag is minimized, and the vertical speed indicator is easy to interpret. Overcontrolling can be minimized by first neutralizing the controls and allowing the pitch attitude to stabilize; then readjusting the pitch attitude by noting the indications of the other pitch instruments.

Occasionally, the vertical speed indicator may be slightly out of calibration. This could result in the instrument indicating a slight climb or descent even when the helicopter is in level flight. If it cannot be readjusted properly, this error must be taken into consideration when using the vertical speed indicator for pitch control. For example, if the vertical speed indicator showed a descent of 100 feet per minute (fpm) when the helicopter was in level flight, you would have to use that indication as level flight. Any deviation from that reading would indicate a change in attitude.

Airspeed Indicator

The airspeed indicator gives an indirect indication of helicopter pitch attitude. With a given power setting and pitch attitude, the airspeed remains constant. If the airspeed increases, the nose is too low and should be raised. If the airspeed decreases, the nose is too high and should be

Instrument flight fundamental:
Attitude + Power = Performance

Indirect indication: A reflection of aircraft pitch-and-bank attitude by the instruments other than the attitude indicator.

Lag: The delay that occurs before an instrument needle attains a stable indication.

lowered. A rapid change in airspeed indicates a large change in pitch attitude, and a slow change in airspeed indicates a small change in pitch attitude. There is very little lag in the indications of the airspeed indicator. If, while making attitude changes, you notice some lag between control application and change of airspeed, it is most likely due to cyclic control lag. Generally, a departure from the desired airspeed, due to an inadvertent pitch attitude change, also results in a change in altitude. For example, an increase in airspeed due to a low pitch attitude results in a decrease in altitude. A correction in the pitch attitude regains both airspeed and altitude.

Bank Control

The bank attitude of a helicopter is the angular relation of its lateral axis and the natural horizon. To maintain a straight course in visual flight, you must keep the lateral axis of the helicopter level with the natural horizon. Assuming the helicopter is in **coordinated** flight, any deviation from a laterally level attitude produces a turn. [Figure 6-4]

Attitude Indicator

The attitude indicator gives a direct indication of the bank attitude of the helicopter. For instrument flight, the miniature aircraft and the horizon bar of the attitude indicator are substituted for the actual helicopter and the natural horizon. Any change in bank attitude of the helicopter is indicated instantly by the miniature aircraft. For proper interpretations of this instrument, you should imagine being in the miniature aircraft. If the helicopter is properly trimmed and the rotor tilts, a turn begins. The turn can be stopped by leveling the miniature aircraft with the horizon bar. The ball in the turn-and-slip indicator should always be kept centered through proper pedal trim.

The angle of bank is indicated by the pointer on the banking scale at the top of the instrument. [Figure 6-5] Small bank angles which may not be seen by observing the miniature aircraft, can easily be determined by referring to the banking scale pointer.

Figure 6-4. *The flight instruments used for bank control are the attitude, heading, and turn indicators.*

Coordinated: Using the controls to maintain or establish various conditions of flight with (1) a minimum disturbance of the forces maintaining equilibrium, or (2) the control action necessary to effect the smoothest changes in equilibrium.

Figure 6-5. *The banking scale at the top of the attitude indicator indicates varying degrees of bank. In this example, the helicopter is banked a little over 10° to the right.*

Pitch-and-bank attitudes can be determined simultaneously on the attitude indicator. Even though the miniature aircraft is not level with the horizon bar, pitch attitude can be established by observing the relative position of the miniature aircraft and the horizon bar.

The attitude indicator may show small misrepresentations of bank attitude during maneuvers which involve turns. This **precession** error can be immediately detected by closely cross-checking the other bank instruments during these maneuvers. Precession normally is noticed when rolling out of a turn. If, on the completion of a turn, the miniature aircraft is level and the helicopter is still turning, make a small change of bank attitude to center the turn needle and stop the movement of the heading indicator.

Heading Indicator

In coordinated flight, the heading indicator gives an indirect indication of the helicopter's bank attitude. When a helicopter is banked, it turns. When the lateral axis of the helicopter is level, it flies straight. Therefore, in coordinated flight, when the heading indicator shows a constant heading, the helicopter is level laterally. A deviation from the desired heading indicates a bank in the direction the helicopter is turning. A small angle of bank is indicated by a slow change of heading; a large angle of bank is indicated by a rapid change of heading. If a turn is noticed, apply opposite cyclic until the heading indicator indicates the desired heading, simultaneously checking that the ball is centered. When making the correction to the desired heading, you should not use a bank angle greater than that required to achieve a standard-rate turn. In addition, if the number of degrees of change is small, limit the bank angle to the number of degrees to be turned. Bank angles greater than these require more skill and precision in attaining the desired results. During straight-and-level flight, the heading indicator is the primary reference for bank control.

Turn Indicator

During coordinated flight, the needle of the turn-and-slip indicator gives an indirect indication of the bank attitude of the helicopter. When the needle is displaced from the vertical position, the helicopter is turning in the direction of the displacement. Thus, if the needle is displaced to the left, the helicopter is turning left. Bringing the needle back to the vertical position with the cyclic produces straight flight. A close observation of the needle is necessary to accurately interpret small deviations from the desired position.

Cross-check the ball of the turn-and-slip indicator to determine that the helicopter is in coordinated flight. If the rotor is laterally level and torque is properly compensated for by pedal pressure, the ball remains in the center. To center the ball, level the helicopter laterally by reference to the other bank instruments, then center the ball with pedal trim. Torque correction pressures vary as you make power changes. Always check the ball following such changes.

Common Errors During Straight-and-Level Flight

1. Failure to maintain altitude.
2. Failure to maintain heading.
3. Overcontrolling pitch and bank during corrections.
4. Failure to maintain proper pedal trim.
5. Failure to cross-check all available instruments.

Precession: The characteristic of a gyroscope that causes an applied force to be felt, not at the point of application, but 90° from that point in the direction of rotation.

Power Control During Straight-and-Level Flight

Establishing specific power settings is accomplished through collective pitch adjustments and throttle control, where necessary. For reciprocating powered helicopters, power indications are observed on the manifold pressure gauge. For turbine powered helicopters, power is observed on the torque gauge. (Since most instrument flight rules (IFR)-certified helicopters are turbine powered, this discussion concentrates on this type of helicopter.)

At any given airspeed, a specific power setting determines whether the helicopter is in level flight, in a climb, or in a descent. For example, cruising airspeed maintained with cruising power results in level flight. If you increase the power setting and hold the airspeed constant, the helicopter climbs. Conversely, if you decrease power and hold the airspeed constant, the helicopter descends. As a rule of thumb, in a turbine-engine powered helicopter, a 10 to 15 percent change in the torque value required to maintain level flight results in a climb or descent of approximately 500 fpm, if the airspeed remains the same.

If the altitude is held constant, power determines the airspeed. For example, at a constant altitude, cruising power results in cruising airspeed. Any deviation from the cruising power setting results in a change of airspeed. When power is added to increase airspeed, the nose of the helicopter pitches up and yaws to the right in a helicopter with a counterclockwise main rotor blade rotation. When power is reduced to decrease airspeed, the nose pitches down and yaws to the left. The yawing effect is most pronounced in single-rotor helicopters, and is absent in helicopters with counter-rotating rotors. To counteract the yawing tendency of the helicopter, apply pedal trim during power changes.

To maintain a constant altitude and airspeed in level flight, coordinate pitch attitude and power control. The relationship between altitude and airspeed determines the need for a change in power and/or pitch attitude. If the altitude is constant and the airspeed is high or low, change the power to obtain the desired airspeed. During the change in power, make an accurate interpretation of the altimeter; then counteract any deviation from the desired altitude by an appropriate change of pitch attitude. If the altitude is low and the airspeed is high, or vice versa, a change in pitch attitude alone may return the helicopter to the proper altitude and airspeed. If both airspeed and altitude are low, or if both are high, a change in both power and pitch attitude is necessary.

To make power control easy when changing airspeed, it is necessary to know the approximate power settings for the various airspeeds which will be flown. When the airspeed is to be changed any appreciable amount, adjust the torque so that it is approximately 5 percent over or under that setting necessary to maintain the new airspeed. As the power approaches the desired setting, include the torque meter in the cross-check to determine when the proper adjustment has been accomplished. As the airspeed is changing, adjust the pitch attitude to maintain a constant altitude. A constant heading should be maintained throughout the change. As the desired airspeed is approached, adjust power to the new cruising power setting and further adjust pitch attitude to maintain altitude. **Overpowering** and **underpowering** torque approximately 5 percent results in a change of airspeed at a moderate rate, which allows ample time to adjust pitch and bank smoothly. The instrument indications for straight-and-level flight at normal cruise, and during the transition from normal cruise to slow cruise are illustrated in figures 6-6 and 6-7. After the airspeed has stabilized at slow cruise, the attitude indicator shows an approximate level pitch attitude.

The altimeter is the primary pitch instrument during level flight, whether flying at a constant airspeed, or during a change in airspeed. Altitude should not change during airspeed transitions. The heading indicator remains the primary bank instrument. Whenever the airspeed is changed any appreciable amount, the torque meter is momentarily the primary instrument for power control. When the airspeed approaches that desired, the airspeed indicator again becomes the primary instrument for power control.

The cross-check of the pitch-and-bank instruments to produce straight-and-level flight should be combined with the power control instruments. With a constant power setting, a normal cross-check should be satisfactory. When changing power, the speed of the cross-check must be increased to cover the pitch-and-bank instruments adequately. This is necessary to counteract any deviations immediately.

Overpowering: Using more power than required for the purpose of achieving a faster rate of airspeed change.

Underpowering: Using less power than required for the purpose of achieving a faster rate of airspeed change.

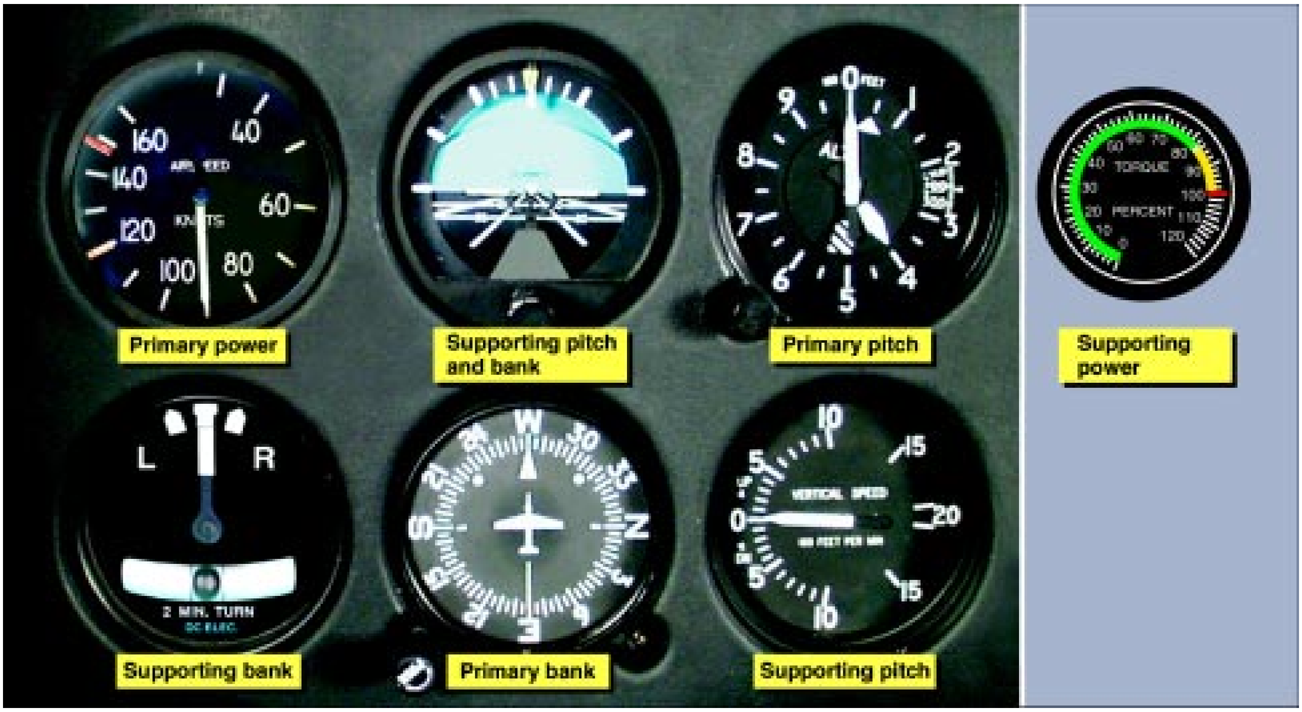


Figure 6-6. *Flight instrument indications in straight-and-level flight at normal cruise speed.*

Figure 6-7. *Flight instrument indications in straight-and-level flight with airspeed decreasing.*

Common Errors During Airspeed Changes

1. Improper use of power.
2. Overcontrolling pitch attitude.
3. Failure to maintain heading.
4. Failure to maintain altitude.
5. Improper pedal trim.

Straight Climbs (Constant Airspeed and Constant Rate)

For any power setting and load condition, there is only one airspeed which will give the most efficient rate of climb. To determine this, you should consult the climb data for the type of helicopter being flown. The **technique** varies according to the airspeed on entry and whether you want to make a constant-airspeed or constant-rate climb.

Entry

To enter a constant-airspeed climb from cruise airspeed, when the climb speed is lower than cruise speed, simultaneously increase power to the climb power setting and adjust pitch attitude to the approximate climb attitude. The increase in power causes the helicopter to start climbing and only very slight back cyclic pressure is needed to complete the change from level to climb attitude. The attitude indicator should be used to accomplish the pitch change. If the transition from level flight to a climb is smooth, the vertical speed indicator shows an immediate upward trend and then stops at a rate appropriate to the stabilized airspeed and attitude. Primary and supporting instruments for climb entry are illustrated in figure 6-8.

When the helicopter stabilizes on a constant airspeed and attitude, the airspeed indicator becomes primary for pitch. The torque meter continues to be primary for power and should be monitored closely to determine if the proper climb power setting is being maintained. Primary and supporting instruments for a stabilized constant-airspeed climb are shown in figure 6-9.

The technique and procedures for entering a constant-rate climb are very similar to those previously described for a constant-airspeed climb. For training purposes, a constant-

Figure 6-8. *Flight instrument indications during climb entry for a constant-airspeed climb.*

Technique: The manner or style in which the procedures are executed.

Figure 6-9. *Flight instrument indications in a stabilized, constant-airspeed climb.*

rate climb is entered from climb airspeed. The rate used is the one that is appropriate for the particular helicopter being flown. Normally, in helicopters with low climb rates, 500 fpm is appropriate, in helicopters capable of high climb rates, use a rate of 1,000 fpm.

To enter a constant-rate climb, increase power to the approximate setting for the desired rate. As power is applied, the airspeed indicator is primary for pitch until the vertical speed approaches the desired rate. At this time, the vertical speed indicator becomes primary for pitch. Change pitch attitude by reference to the attitude indicator to maintain the desired vertical speed. When the vertical speed indicator becomes primary for pitch, the airspeed indicator becomes primary for power. Primary and supporting instruments for a stabilized constant-rate climb are illustrated in figure 6-10. Adjust power to maintain desired airspeed. Pitch attitude and power corrections should be closely coordinated. To illustrate this, if the vertical speed is correct but the airspeed is low, add power. As power is increased, it may be necessary to lower the pitch attitude slightly to avoid increasing the vertical rate. Adjust the pitch attitude smoothly to avoid over-controlling. Small power corrections usually will be sufficient to bring the airspeed back to the desired indication.

Level-Off

The level-off from a constant-airspeed climb must be started before reaching the desired altitude. Although the amount of lead varies with the helicopter being flown and your piloting technique, the most important factor is vertical speed. As a rule of thumb, use 10 percent of the vertical velocity as your lead point. For example, if the rate of climb is 500 fpm, initiate the level-off approximately 50 feet before the desired altitude. When the proper lead altitude is reached, the altimeter becomes primary for pitch. Adjust the pitch attitude to the level flight attitude for that airspeed. Cross-check the altimeter and vertical speed indicator to determine when level flight has been attained at the desired altitude. To level off at cruise airspeed, if this speed is higher than climb airspeed, leave the power at the climb power setting until the airspeed approaches cruise airspeed, then reduce it to the cruise power setting.

Figure 6-10. *Flight instrument indications in a stabilized constant-rate climb.*

The level-off from a constant-rate climb is accomplished in the same manner as the level-off from a constant-airspeed climb.

Straight Descents (Constant Airspeed and Constant Rate)

A descent may be performed at any normal airspeed the helicopter is capable of, but the airspeed must be determined prior to entry. The technique is determined by whether you want to perform a constant-airspeed or a constant-rate descent.

Entry

If your airspeed is higher than descending airspeed, and you wish to make a constant-airspeed descent at the descending airspeed, reduce power to the descending power setting and maintain a constant altitude using cyclic pitch control. When you approach the descending airspeed, the airspeed indicator becomes primary for pitch, and the torque meter is primary for power. As you hold the airspeed constant, the helicopter begins to descend. For a constant-rate descent, reduce the power to the approximate setting for the desired rate. If the descent is started at the descending airspeed, the airspeed indicator is primary for pitch until the vertical speed indicator approaches the desired rate. At this time, the vertical speed indicator becomes primary for pitch, and the airspeed indicator becomes primary for power. Coordinate power and pitch attitude control as was described earlier for constant-rate climbs.

Level-Off

The level-off from a constant-airspeed descent may be made at descending airspeed or at cruise airspeed, if this is higher than descending airspeed. As in a climb level-off, the amount of lead depends on the rate of descent and control technique. For a level-off at descending airspeed, the lead should be approximately 10 percent of the vertical speed. At the lead altitude, simultaneously increase power to the setting necessary to maintain descending airspeed in level flight. At this point, the altimeter becomes primary for pitch, and the airspeed indicator becomes primary for power.

To level off at a higher airspeed than descending airspeed, increase the power approximately 100 to 150 feet prior to reaching the desired altitude. The power setting should be that which is necessary to maintain the desired airspeed in level flight. Hold the vertical speed constant until approximately 50 feet above the desired altitude. At this point, the altimeter becomes primary for pitch, and the airspeed indicator becomes primary for power. The level-off from a constant-rate descent should be accomplished in the same manner as the level-off from a constant-airspeed descent.

Common Errors During Straight Climbs and Descents

1. Failure to maintain heading.
2. Improper use of power.
3. Poor control of pitch attitude.
4. Failure to maintain proper pedal trim.
5. Failure to level off on desired altitude.

Turns

When making turns by reference to the flight instruments, they should be made at a precise rate. Turns described in this chapter are those which do not exceed a standard rate of 3° per second as indicated on the turn-and-slip indicator. True airspeed determines the angle of bank necessary to maintain a standard-rate turn. A rule of thumb to determine the approximate angle of bank required for a standard-rate turn is to divide your airspeed by 10 and add one-half the result. For example, at 60 knots, approximately 9° of bank is required (60 ÷ 10 = 6 + 3 = 9); at 80 knots, approximately 12° of bank is needed for a standard-rate turn.

To enter a turn, apply lateral cyclic in the direction of the desired turn. The entry should be accomplished smoothly, using the attitude indicator to establish the approximate bank angle. When the turn indicator indicates a standard-rate turn, it becomes primary for bank. The attitude indicator now becomes a supporting instrument. During level turns, the altimeter is primary for pitch, and the airspeed indicator is primary for power. Primary and supporting instruments for a stabilized standard-rate turn are illustrated in figure 6-11. If an increase in power is required to maintain airspeed, slight forward cyclic pressure may be required since the helicopter tends to pitch up as collective pitch angle is increased. Apply pedal trim, as required, to keep the ball centered.

Figure 6-11. *Flight instrument indications for a standard-rate turn to the left.*

To recover to straight-and-level flight, apply cyclic in the direction opposite the turn. The rate of roll-out should be the same as the rate used when rolling into the turn. As you initiate the turn recovery, the attitude indicator becomes primary for bank. When the helicopter is approximately level, the heading indicator becomes primary for bank as in straight-and-level flight. Cross-check the airspeed indicator and ball closely to maintain the desired airspeed and pedal trim.

Turns to a Predetermined Heading

A helicopter turns as long as its lateral axis is tilted; therefore, the recovery must start before the desired heading is reached. The amount of lead varies with the rate of turn and your piloting technique.

As a guide, when making a 3° per second rate of turn, use a lead of one-half the bank angle. For example, if you are using a 12° bank angle, use half of that, or 6°, as the lead point prior to your desired heading. Use this lead until you are able to determine the exact amount required by your particular technique. The bank angle should never exceed the number of degrees to be turned. As in any standard-rate turn, the rate of recovery should be the same as the rate for entry. During turns to predetermined headings, cross-check the primary and supporting pitch, bank, and power instruments closely.

Timed Turns

A timed turn is a turn in which the clock and turn-and-slip indicator are used to change heading a definite number of degrees in a given time. For example, using a standard-rate turn, a helicopter turns 45° in 15 seconds. Using a half-standard-rate turn, the helicopter turns 45° in 30 seconds. Timed turns can be used if your heading indicator becomes inoperative.

Prior to performing timed turns, the turn coordinator should be **calibrated** to determine the accuracy of its indications. To do this, establish a standard-rate turn by referring to the turn-and-slip indicator. Then as the sweep second hand of the clock passes a cardinal point (12, 3, 6, or 9), check the heading on the heading indicator. While holding the indicated rate of turn constant, note the heading changes at 10-second intervals. If the helicopter turns more or less than 30 degrees in that interval, a smaller or larger deflection of the needle is necessary to produce a standard-rate turn. When you have calibrated the turn-and-slip indicator during turns in each direction, note the corrected deflections, if any, and apply them during all timed turns.

You use the same cross-check and control technique in making timed turns that you use to make turns to a predetermined heading, except that you substitute the clock for the heading indicator. The needle of the turn-and-slip indicator is primary for bank control, the altimeter is primary for pitch control, and the airspeed indicator is primary for power control. Begin the roll-in when the clock's second hand passes a cardinal point, hold the turn at the calibrated standard-rate indication, or half-standard-rate for small changes in heading, and begin the roll-out when the computed number of seconds has elapsed. If the roll-in and roll-out rates are the same, the time taken during entry and recovery need not be considered in the time computation.

If you practice timed turns with a full instrument panel, check the heading indicator for the accuracy of your turns. If you execute the turns without the heading indicator, use the magnetic compass at the completion of the turn to check turn accuracy, taking compass deviation errors into consideration.

Change of Airspeed in Turns

Changing airspeed in turns is an effective maneuver for increasing your proficiency in all three basic instrument skills. Since the maneuver involves simultaneous changes in all components of control, proper execution requires a rapid cross-check and interpretation, as well as smooth control. Proficiency in the maneuver also contributes to your confidence in the instruments during attitude and power changes involved in more complex maneuvers.

Pitch and power control techniques are the same as those used during airspeed changes in straight-and-level flight. As discussed previously, the angle of bank necessary for a given rate of turn is proportional to the true airspeed. Since the turns are executed at standard rate, the angle of bank must be varied in direct proportion to the airspeed change in order to maintain a constant rate of turn. During a reduction of airspeed, you must decrease the angle of bank and increase the pitch attitude to maintain altitude and a standard-rate turn.

Calibrated: The instrument indication was compared with a standard value to determine the accuracy of the instrument.

The altimeter and the needle on the turn indicator should remain constant throughout the turn. The altimeter is primary for pitch control, and the turn needle is primary for bank control. The torque meter is primary for power control while the airspeed is changing. As the airspeed approaches the new indication, the airspeed indicator becomes primary for power control.

Two methods of changing airspeed in turns may be used. In the first method, airspeed is changed after the turn is established. In the second method, the airspeed change is initiated simultaneously with the turn entry. The first method is easier, but regardless of the method used, the rate of cross-check must be increased as you reduce power. As the helicopter decelerates, check the altimeter and vertical speed indicator for needed pitch changes, and the bank instruments for needed bank changes. If the needle of the turn-and-slip indicator shows a deviation from the desired deflection, change the bank. Adjust pitch attitude to maintain altitude. When the airspeed approaches that desired, the airspeed indicator becomes primary for power control. Adjust the torque meter to maintain the desired airspeed. Use pedal trim to ensure the maneuver is coordinated.

Until your control technique is very smooth, frequently cross-check the attitude indicator to keep from overcontrolling and to provide approximate bank angles appropriate for the changing airspeeds.

Compass Turns

The use of gyroscopic heading indicators make heading control very easy. However, if the heading indicator fails or your helicopter does not have one installed, you must use the magnetic compass for heading reference. When making compass-only turns, you need to adjust for the lead or lag created by acceleration and deceleration errors so that you roll out on the desired heading. When turning to a heading of north, the lead for the roll-out must include the number of degrees of your latitude plus the lead you normally use in recovery from turns. During a turn to a south heading, maintain the turn until the compass passes south the number of degrees of your latitude, minus your normal roll-out lead. For example, when turning from an easterly direction to north, where the latitude is 30°, start the roll-out when the compass reads 037° (30° plus one-half the 15° angle of bank, or whatever amount is appropriate for your rate of roll-out). When turning from an easterly direction to south, start the roll-out when the magnetic compass reads 203° (180° plus 30° minus one-half the angle of bank). When making similar turns from a westerly direction, the appropriate points at which to begin your roll-out would be 323° for a turn to north, and 157° for a turn to south.

30° Bank Turn

A turn using 30° of bank is seldom necessary, or advisable, in instrument meteorological conditions (IMC) and is considered an unusual attitude in a helicopter. However, it is an excellent maneuver to increase your ability to react quickly and smoothly to rapid changes of attitude. Even though the entry and recovery technique are the same as for any other turn, you will probably find it more difficult to control pitch because of the decrease in vertical lift as the bank increases. Also, because of the decrease in vertical lift, there is a tendency to lose altitude and/or airspeed. Therefore, to maintain a constant altitude and airspeed, additional power is required. You should not initiate a correction, however, until the instruments indicate the need for one. During the maneuver, note the need for a correction on the altimeter and vertical speed indicator, then check the indications on the attitude indicator, and make the necessary adjustments. After you have made this change, again check the altimeter and vertical speed indicator to determine whether or not the correction was adequate.

Climbing and Descending Turns

For climbing and descending turns, the techniques described earlier for straight climbs and descents and those for standard-rate turns are combined. For practice, start the climb or descent and turn simultaneously. The primary and supporting instruments for a stabilized constant airspeed left climbing turn are illustrated in figure 6-12. The level-off from a climbing or descending turn is the same as the level-off from a straight climb or descent. To return to straight-and-level flight, you may stop the turn and then level off, level off and then stop the turn, or simultaneously level off and stop the turn. During climbing and descending turns, keep the ball of the turn indicator centered with pedal trim.

Figure 6-12. *Flight instrument indications for a stabilized left climbing turn at a constant airspeed.*

Common Errors During Turns

1. Failure to maintain desired turn rate.
2. Failure to maintain altitude in level turns.
3. Failure to maintain desired airspeed.
4. Variation in the rate of entry and recovery.
5. Failure to use proper lead in turns to a heading.
6. Failure to properly compute time during timed turns.
7. Failure to use proper leads and lags during the compass turns.
8. Improper use of power.
9. Failure to use proper pedal trim.

Unusual Attitudes

Any maneuver not required for normal helicopter instrument flight is an unusual attitude and may be caused by any one or a combination of factors such as turbulence, disorientation, instrument failure, confusion, preoccupation with cockpit duties, carelessness in cross-checking, errors in instrument interpretation, or lack of proficiency in aircraft control. Due to the instability characteristics of the helicopter, unusual attitudes can be extremely critical. As soon as you detect an unusual attitude, make a recovery to straight-and-level flight as soon as possible with a minimum loss of altitude.

To recover from an unusual attitude, correct bank-and-pitch attitude, and adjust power as necessary. All components are changed almost simultaneously, with little lead of one over the other. You must be able to perform this task with and without the attitude indicator. If the helicopter is in a climbing or descending turn, correct bank, pitch, and power. The bank attitude should be corrected by referring to the turn-and-slip indicator and attitude indicator. Pitch attitude should be corrected by reference to the altimeter, airspeed indicator, vertical speed indicator, and attitude indicator. Adjust power by referring to the airspeed indicator and torque meter.

Since the displacement of the controls used in recoveries from unusual attitudes may be greater than those for normal flight, take care in making adjustments as straight-and-level flight is approached. Cross-check the other instruments closely to avoid overcontrolling.

Common Errors During Unusual Attitude Recoveries

1. Failure to make proper pitch correction.
2. Failure to make proper bank correction.
3. Failure to make proper power correction.
4. Overcontrolling pitch and/or bank attitude.
5. Overcontrolling power.
6. Excessive loss of altitude.

Emergencies

Emergencies under instrument flight are handled similarly to those occurring during VFR flight. A thorough knowledge of the helicopter and its systems, as well as good aeronautical knowledge and judgment, prepares you to better handle emergency situations. Safe operations begin with preflight planning and a thorough preflight inspection. Plan your route of flight so there are adequate landing sites in the event you have to make an emergency landing. Make sure you have all your resources, such as maps, publications, flashlights, and fire extinguishers readily available for use in an emergency.

During any emergency, you should first fly the aircraft. This means that you should make sure the helicopter is under control, including the determination of emergency landing sites. Then perform the emergency checklist memory items, followed by written items in the rotorcraft flight manual (RFM). Once all these items are under control, you should notify air traffic control (ATC). Declare any emergency on the last assigned ATC frequency, or if one was not issued, transmit on the emergency frequency 121.5. Set the transponder to the emergency squawk code 7700. This code triggers an alarm or a special indicator in radar facilities.

Most in-flight emergencies, including low fuel and a complete electrical failure, require you to **land as soon as possible**. In the event of an electrical fire, turn all nonessential equipment off and **land immediately**. Some essential electrical instruments, such as the attitude indicator, may be required for a safe landing. A navigation radio failure may not require an immediate landing as long as the flight can continue safely. In this case, you should **land as soon as practical**. ATC may be able to provide vectors to a safe landing area. For the specific details on what to do during an emergency, you should refer to the RFM for the helicopter you are flying.

Autorotations

Both straight-ahead and turning autorotations should be practiced by reference to instruments. This training will ensure that you can take prompt corrective action to maintain positive aircraft control in the event of an engine failure.

To enter autorotation, reduce collective pitch smoothly to maintain a safe rotor RPM and apply pedal trim to keep the ball of the turn-and-slip indicator centered. The pitch attitude of the helicopter should be approximately level as shown by the attitude indicator. The airspeed indicator is the primary pitch instrument and should be adjusted to the recommended autorotation speed. The heading indicator is primary for bank in a straight-ahead autorotation. In a turning autorotation, a standard-rate turn should be maintained by reference to the needle of the turn-and-slip indicator.

Common Errors During Autorotations

1. Uncoordinated entry due to improper pedal trim.
2. Poor airspeed control due to improper pitch attitude.
3. Poor heading control in straight-ahead autorotations.
4. Failure to maintain proper rotor RPM.
5. Failure to maintain a standard-rate turn during turning autorotations.

Servo Failure

Most helicopters certified for single-pilot IFR flight are required to have autopilots, which greatly reduces pilot workload. If an autopilot servo fails, however, you have to resume manual control of the helicopter. How much your workload increases, depends on which servo fails. If a cyclic servo fails, you may want to land immediately as the workload increases tremendously. If an antitorque or collective servo fails, you might be able to continue to the next suitable landing site.

Land as soon as possible: Land without delay at the nearest suitable area, such as an open field, at which a safe approach and landing is assured.

Land immediately: The urgency of the landing is paramount. The primary consideration is to ensure the survival of the occupants. Landing in trees, water, or other unsafe areas should be considered only as a last resort.

Land as soon as practical: The landing site and duration of flight are at the discretion of the pilot. Extended flight beyond the nearest approved landing area is not recommended.

Instrument Takeoff

The procedures and techniques described here should be modified, as necessary, to conform with those set forth in the operating instructions for the particular helicopter being flown. During training, **instrument takeoffs** should not be attempted except when receiving instruction from an appropriately certificated, proficient flight instructor pilot.

Adjust the miniature aircraft in the attitude indicator, as appropriate, for the aircraft being flown. After the helicopter is aligned with the runway or takeoff pad, to prevent forward movement of a helicopter equipped with a wheel-type landing gear, set the parking brakes or apply the toe brakes. If the parking brake is used, it must be unlocked after the takeoff has been completed. Apply sufficient friction to the collective pitch control to minimize overcontrolling and to prevent creeping. Excessive friction should be avoided since this limits collective pitch movement.

After checking all instruments for proper indications, start the takeoff by applying collective pitch and a predetermined power setting. Add power smoothly and steadily to gain airspeed and altitude simultaneously and to prevent settling to the ground. As power is applied and the helicopter becomes airborne, use the antitorque pedals initially to maintain the desired heading. At the same time, apply forward cyclic to begin accelerating to climbing airspeed. During the initial acceleration, the pitch attitude of the helicopter, as read on the attitude indicator, should be one to two bar widths low. The primary and supporting instruments after becoming airborne are illustrated in figure 6-13. As the airspeed increases to the appropriate climb airspeed, adjust pitch gradually to climb attitude. As climb airspeed is reached, reduce power to the climb power setting and transition to a fully coordinated straight climb.

During the initial climb out, minor heading corrections should be made with pedals only until sufficient airspeed is attained to transition to fully coordinated flight. Throughout the instrument takeoff, instrument cross-check and interpretations must be rapid and accurate, and aircraft control positive and smooth.

Common Errors During Instrument Takeoffs

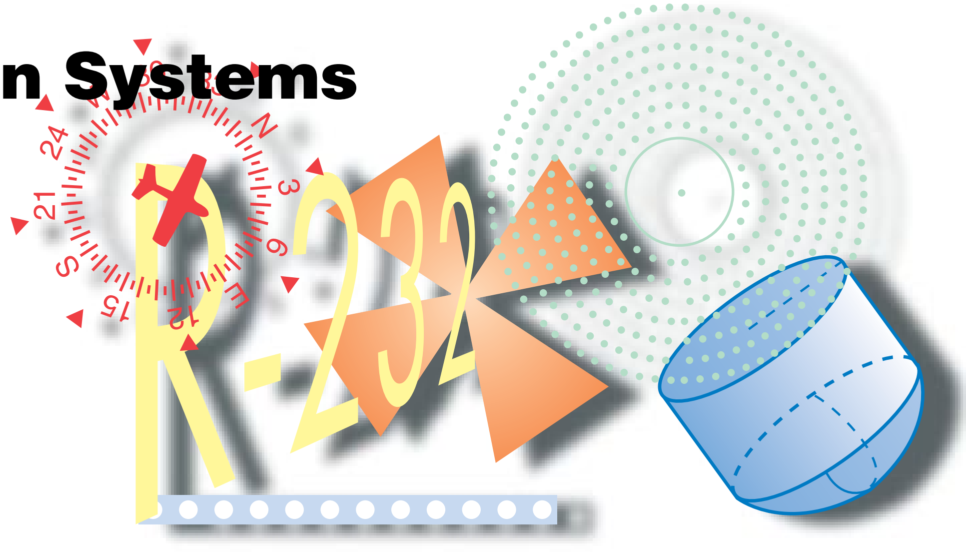
1. Failure to maintain heading.
2. Overcontrolling pedals.
3. Failure to use required power.
4. Failure to adjust pitch attitude as climbing airspeed is reached.

Figure 6-13. *Flight instrument indications during an instrument takeoff.*

Instrument takeoff: Using the instruments rather than outside visual cues to maintain runway heading and execute a safe takeoff.

Chapter 7

Navigation Systems



Introduction

This chapter provides the basic radio principles applicable to navigation equipment, as well as an operational knowledge of how to use these systems in instrument flight. This information provides the framework for all instrument procedures, including departure procedures (DPs), holding patterns, and approaches, because each of these maneuvers consist mainly of accurate attitude instrument flying and accurate tracking using navigation systems.

Basic Radio Principles

A **radio wave** is an electromagnetic wave (EM wave) with frequency characteristics that make it useful in radio. The wave will travel long distances through space (in or out of the atmosphere) without losing too much strength. The antenna is used to convert it from an electric current into a radio wave so it can travel through space to the receiving antenna which converts it back into an electric current.

How Radio Waves Propagate

All matter has a varying degree of conductivity or resistance to radio waves. The Earth itself acts as the greatest resistor to radio waves. Radiated energy that travels near the ground induces a voltage in the ground that subtracts energy from the wave, decreasing the strength of the wave as the distance from the antenna becomes greater. Trees, buildings, and mineral deposits affect the strength to varying degrees. Radiated energy in the upper atmosphere is likewise affected as the energy of radiation is absorbed by molecules of air, water, and dust. The characteristics of radio wave propagation vary according to the signal frequency, and the design, use, and limitations of the equipment.

Ground Wave

The ground wave travels across the surface of the Earth. You can best imagine the ground wave's path as being in a tunnel or alley bounded by the surface of the Earth and by the ionosphere, which keeps it from going out into space. Generally, the lower the frequency, the farther the signal will travel.

Ground waves are usable for navigation purposes because they reliably and predictably travel the same route, day after day, and are not influenced by too many outside factors. The ground wave frequency range is generally from the lowest frequencies in the radio range (perhaps as low as 100 Hz) up to approximately 1,000 kHz (1 MHz). Although there is a ground wave component to frequencies above this, even to 30 MHz, the ground wave at these higher frequencies loses strength over very short distances.

Radio wave: An electromagnetic wave (EM wave) with frequency characteristics useful for radio transmission.

Sky Wave

The sky wave, at frequencies of 1 to 30 MHz, is good for long distances because these frequencies are refracted or "bent" by the ionosphere, causing the signal to be sent back to Earth from high in the sky and received great distances away. [Figure 7-1] Used by high frequency (HF) radios in aircraft, messages can be sent across oceans using only 50 to 100 watts of power. Frequencies that produce a sky wave are not used for navigation because the pathway of the signal from transmitter to receiver is highly variable. The wave is "bounced" off of the ionosphere, which is always changing due to the varying amount of the sun's radiation reaching it (night/day and seasonal variations, sunspot activity, etc.). The sky wave is not reliable for navigation purposes.

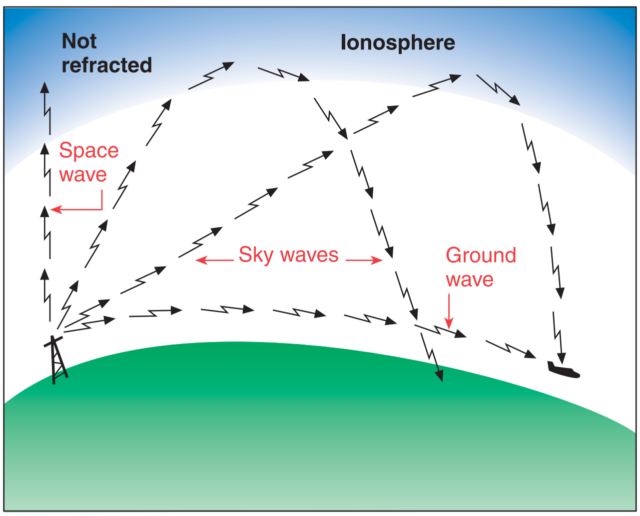


Figure 7-1. *Ground, space, and sky wave propagation.*

For aeronautical communication purposes, the sky wave (HF) is about 80 to 90 percent reliable. HF is being gradually replaced by satellite communication which is more reliable.

Space Wave

Radio waves of 15 MHz and above (all the way up to many GHz), when able to pass through the ionosphere, are considered space waves. Most navigation systems operate with their signals propagating as space waves. Frequencies above 100 MHz have nearly no ground or sky wave components. They are space waves, but (except for global positioning system (GPS)) the navigation signal is used before it reaches the ionosphere so the effect of the ionosphere, which can cause some propagation errors, is minimal. GPS errors caused by passage through the ionosphere are significant and are corrected for by the GPS receiver system.

Space waves have another characteristic of concern to users. Space waves reflect off hard objects and may be blocked if the object is between the transmitter and the receiver. Site and terrain error, as well as **propeller/rotor modulation error** in very-high omnidirectional range (VOR) systems is caused by this bounce. Instrument landing system (ILS) course distortion is also the result of this phenomenon, which led to the need for establishment of ILS **critical areas**.

Generally, space waves are "line of sight" receivable, but those of lower frequencies will "bend" over the horizon somewhat. Since the VOR signal at 108 to 118 MHz is a lower frequency than distance measuring equipment (DME) at 962 to 1213 MHz, when an aircraft is flown "over the horizon" from a VOR/DME station, the DME will normally be the first to stop functioning.

Disturbances to Radio Wave Reception

Static distorts the radio wave and interferes with normal reception of communications and navigation signals. Low-frequency airborne equipment such as automatic direction finder (ADF) and long range navigation (LORAN) are particularly subject to static disturbance. Using very-high frequency (VHF) and ultra-high frequency (UHF) frequencies avoids many of the discharge noise effects. Static noise heard on navigation or communication radio frequencies may be a warning of interference with navigation instrument displays. Some of the problems caused by precipitation static (P-static) are:

- Complete loss of VHF communications.
- Erroneous magnetic compass readings.
- Aircraft flies with one wing low while using the autopilot.
- High-pitched squeal on audio.
- Motorboat sound on audio.
- Loss of all avionics.
- Very-low frequency (VLF) navigation system inoperative.
- Erratic instrument readouts.
- Weak transmissions and poor radio reception.
- St. Elmo's Fire.

Propeller/rotor modulation error: Certain propeller RPM settings or helicopter rotor speeds can cause the VOR course deviation indicator (CDI) to fluctuate as much as ±6°. Pilots should check for this phenomenon prior to reporting a VOR station or aircraft equipment for unsatisfactory operation.

Critical areas: Most ILS installations are subject to signal interference by surface vehicles, aircraft, or both. As a result, areas are established near each localizer and glide-slope antenna so air traffic control (ATC) can steer aircraft away from these areas.

Nondirectional Radio Beacon (NDB)

Description

The nondirectional beacon (NDB) is a ground-based radio transmitter that transmits radio energy in all directions. The ADF, when used with an NDB, determines the bearing from the aircraft to the transmitting station. The indicator may be mounted in a separate instrument in the aircraft panel. [Figure 7-2] The ADF needle points to the NDB ground station to determine the **relative bearing (RB)** to the transmitting station. **Magnetic heading (MH)** plus RB equals the **magnetic bearing (MB)** to the station.

Figure 7-2. *ADF indicator instrument and receiver.*

NDB Components

The ground equipment, the NDB, transmits in the frequency range of 190 to 535 kHz. Most ADFs will also tune the AM broadcast band frequencies above the NDB band (550 to 1650 kHz). However, these frequencies are not approved for navigation because stations do not continuously identify themselves, and they are much more susceptible to sky wave propagation especially from dusk to dawn. NDB stations are capable of voice transmission and are often used for transmitting the automated weather observing system (AWOS). The aircraft must be in operational range of the NDB. Coverage depends on the strength of the transmitting station. Before relying on ADF indications, identify the station by listening to the Morse code identifier. NDB stations are usually two letters or an alpha-numeric combination.

ADF Components

The airborne equipment includes two antennas, a receiver, and the indicator instrument. The "sense" antenna (non-directional) receives signals with nearly equal efficiency from all directions. The "loop" antenna receives signals better from two directions (bidirectional). When the loop and sense antenna inputs are processed together in the ADF radio, the result is the ability to receive a radio signal well in all directions but one, thus resolving all directional ambiguity.

The indicator instrument can be one of three kinds: the fixed-card ADF, movable-card ADF, or the radio magnetic indicator (RMI). The fixed-card ADF (also known as the relative bearing indicator (RBI)), always indicates zero at the top of the instrument, and the needle indicates the RB to the station. Figure 7-3 indicates an RB of 135°, and if the MH is 45°, the MB to the station is 180°. (MH + RB = MB to the station.)

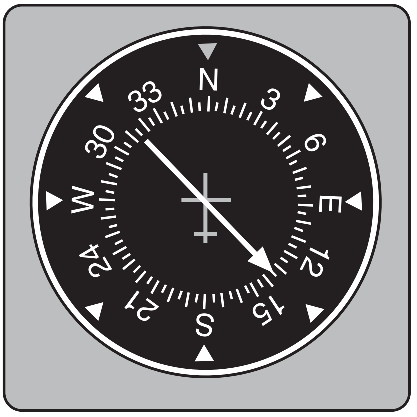


Figure 7-3. *Relative bearing (RB) on a fixed-card indicator.*

The movable-card ADF allows the pilot to rotate the aircraft's present heading to the top of the instrument so that the head of the needle indicates MB to the station, and the tail indicates MB from the station. Figure 7-4 indicates a heading of 45°, the MB to the station is 180°, and the MB from the station is 360°.

Relative bearing: The number of degrees measured clockwise between the heading of the aircraft and the direction from which the bearing is taken.

Magnetic heading (MH): The direction an aircraft is pointed with respect to magnetic north.

Magnetic bearing (MB): The direction to or from a radio transmitting station measured relative to magnetic north.

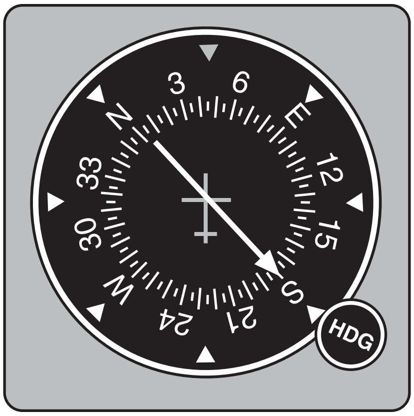


Figure 7-4. *Relative bearing (RB) on a movable-card indicator.*

The RMI differs from the movable-card ADF in that it automatically rotates the azimuth card (remotely controlled by a gyrocompass) to represent aircraft heading. The RMI has two needles, which can be used to indicate navigation information from either the ADF or the VOR receivers. When a needle is being driven by the ADF, the head of the needle indicates the MB TO the station tuned on the ADF receiver. The tail of the needle is the bearing FROM the station. When a needle of the RMI is driven by a VOR receiver, the needle indicates where the aircraft is radially with respect to the VOR station. The needle points to the bearing TO the station, as read on the azimuth card. The tail of the needle points to the radial of the VOR the aircraft is currently on or crossing. Figure 7-5 indicates a heading of 005°, the MB to the station is 015°, and the MB from the station is 195°.

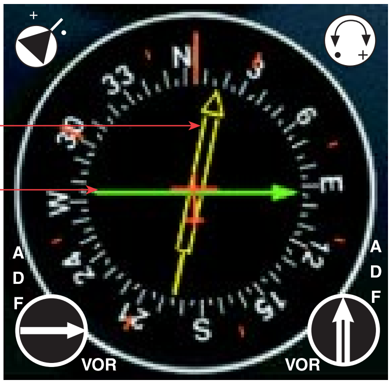


Figure 7-5. *Radio magnetic indicator (RMI).*

Function of ADF

The ADF can be used to plot your position, track inbound and outbound, and intercept a bearing. These procedures are used to execute holding patterns and nonprecision instrument approaches.

Orientation

The ADF needle points TO the station, regardless of aircraft heading or position. The RB indicated is thus the angular relationship between the aircraft heading and the station, measured clockwise from the nose of the aircraft. Think of the nose/tail and left/right needle indications, visualizing the ADF dial in terms of the longitudinal axis of the aircraft. When the needle points to 0°, the nose of the aircraft points directly to the station; with the pointer on 210°, the station is 30° to the left of the tail; with the pointer on 090°, the station is off the right wingtip. The RB does not by itself indicate aircraft position. The RB must be related to aircraft heading in order to determine direction to or from the station.

Station Passage

When you are near the station, slight deviations from the desired track result in large deflections of the needle. Therefore, it is important to establish the correct drift correction angle as soon as possible. Make small heading corrections (not over 5°) as soon as the needle shows a deviation from course, until it begins to rotate steadily toward a wingtip position or shows erratic left/right oscillations. You are abeam a station when the needle points to the 90° or 270° position. Hold your last corrected heading constant, and time station passage when the needle shows either wingtip position or settles at or near the 180° position. The time interval from the first indications of station proximity to positive station passage varies with altitude—a few seconds at low levels to 3 minutes at high altitude.

Homing

The ADF may be used to "home" in on a station. **Homing** is flying the aircraft on any heading required to keep the needle pointing directly to the 0° RB position. To home into a station, tune the station, identify the Morse code signal, then turn the aircraft to bring the ADF azimuth needle to the 0° RB position. Turns should be made using the heading indicator. When the turn is complete, check the ADF needle and make small corrections as necessary.

Homing: Flying the aircraft on any heading required to keep the needle pointing directly to the 0° RB position.

Figure 7-6 illustrates homing starting from an initial MH of 050° and an RB of 300°, indicating a 60° left turn is needed to produce an RB of zero. Turn left, rolling out at 50° minus 60° equals 350°. Small heading corrections are then made to zero the ADF needle.

If there is no wind, the aircraft will home to the station on a direct track over the ground. With a crosswind, the aircraft will follow a circuitous path to the station on the downwind side of the direct track to the station.

Tracking

Tracking uses a heading that will maintain the desired track to or from the station regardless of crosswind conditions. Interpretation of the heading indicator and needle is done to maintain a constant MB to or from the station.

To track inbound, turn to the heading that will produce a zero RB. Maintain this heading until off-course drift is indicated by displacement of the needle, which will occur if there is a crosswind (needle moving left = wind from the left; needle moving right = wind from the right). A rapid rate of bearing change with a constant heading indicates either a strong crosswind or proximity to the station, or both. When there is a definite (2° to 5°) change in needle reading, turn in the direction of needle deflection to intercept the initial MB. The angle of interception must be greater than the number of degrees of drift. The intercept angle depends on the rate of drift, the aircraft speed, and station proximity. Initially, it is standard to double the RB when turning toward your course.

For example, if your heading equals your course and the needle points 10° left, turn 20° left. [Figure 7-7] When the needle is deflected 20° (deflection = interception angle), track has been intercepted. The aircraft is on track as long as the RB remains the same number of degrees as the **wind correction angle (WCA)**. Lead the interception to avoid overshooting the track. Turn 10° toward the inbound course. You are now inbound with a 10° left correction angle.

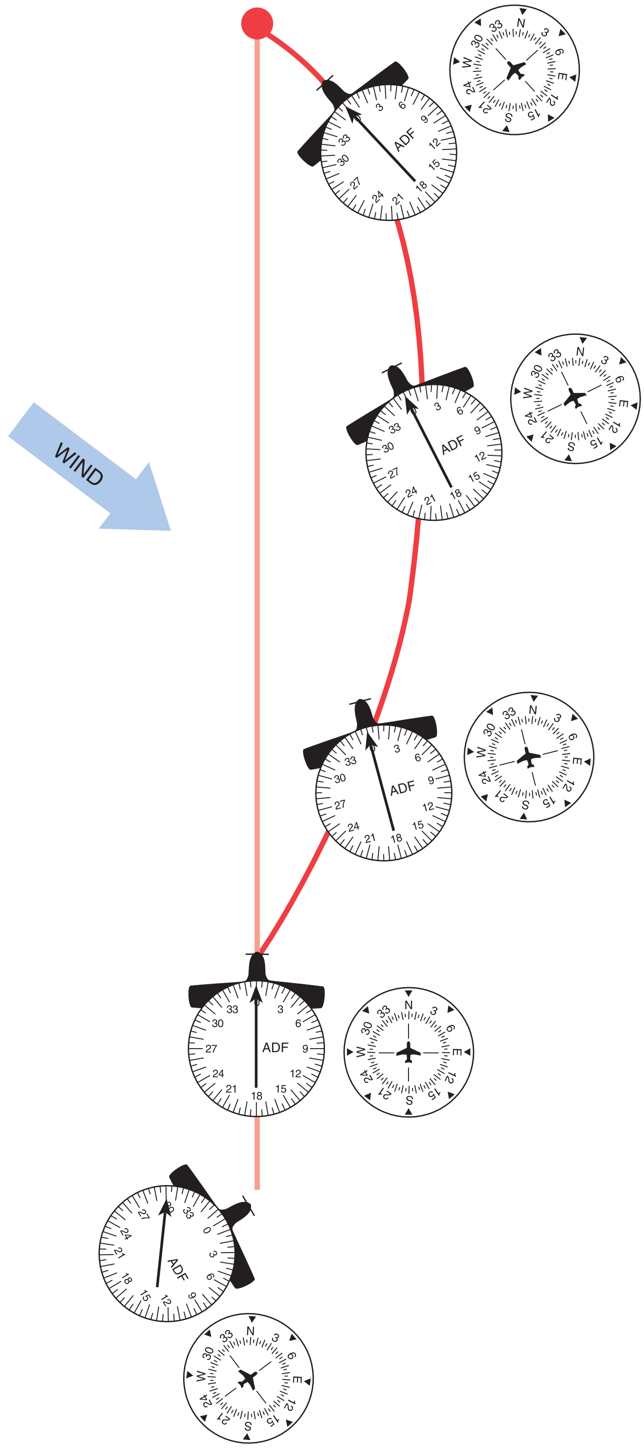


Figure 7-6. *ADF homing with a crosswind.*

Tracking: Flying a heading that will maintain the desired track to or from the station regardless of crosswind conditions.

Wind correction angle (WCA): The angle between the desired track and the heading of the aircraft necessary to keep the aircraft tracking over the desired track.

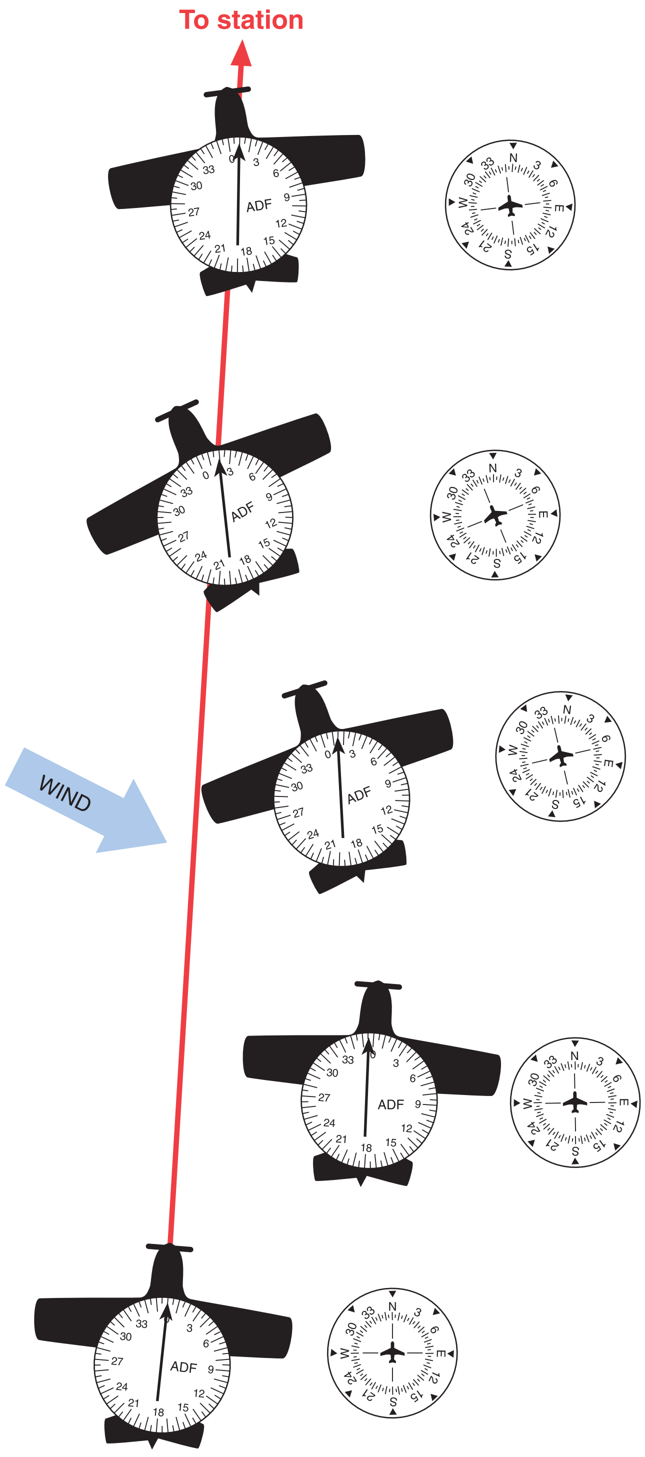


Figure 7-7. *ADF tracking inbound.*

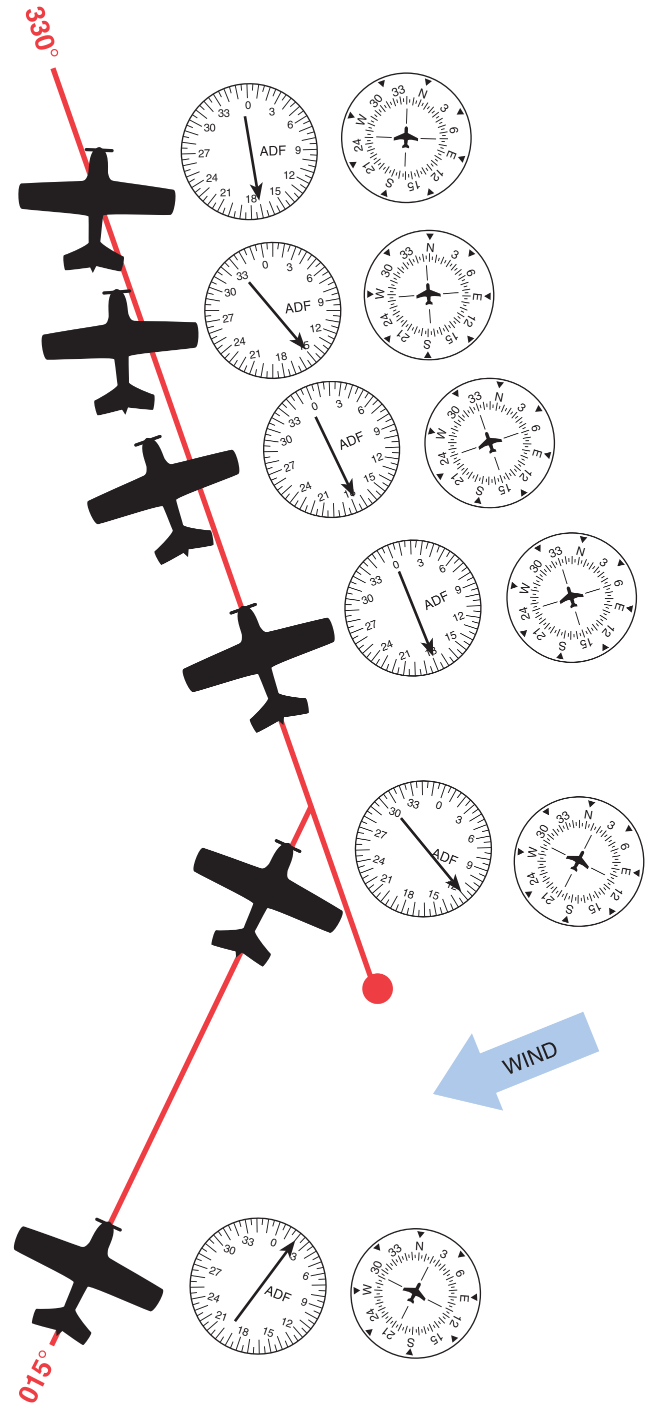


Figure 7-8. *ADF interception and tracking outbound.*

Note that in figure 7-7, for the aircraft closest to the station, the WCA is 10° left and the RB is 10° right. If those values do not change, the aircraft will track directly to the station. If you observe off-course deflection in the original direction, turn again to the original interception heading. When the desired course has been re-intercepted, turn 5° toward the inbound course, proceeding inbound with a 15° drift correction. If the initial 10° drift correction is excessive, as shown by needle deflection away from the wind, turn to parallel the desired course and let the wind drift you back on course. When the needle is again zeroed, turn into the wind with a reduced drift correction angle.

To track outbound, the same principles apply: needle moving left = wind from the left, needle moving right = wind from the right. Wind correction is made toward the needle deflection. The only exception is that, while the turn to establish the WCA is being made, the direction of the azimuth needle deflections is reversed. When tracking inbound, needle deflection decreases while turning to establish the WCA, and needle deflection increases when tracking outbound. Note the example of course interception and outbound tracking in figure 7-8.

Intercepting Bearings

ADF orientation and tracking procedures may be applied to intercept a specified inbound or outbound MB. To intercept an *inbound* bearing of 355°, the following steps may be used. [Figure 7-9]

1. Determine your position in relation to the station by paralleling the desired inbound bearing. Turn to a heading of 355°.
2. Note whether the station is to the right or left of the nose position. Determine the number of degrees of needle deflection from the zero position, and double this amount for the interception angle. The needle is indicating a 40° RB to the right.
3. Turn the aircraft toward the desired MB the number of degrees determined for the interception angle. Turn right 80° to a heading of 75°.
4. Maintain the interception heading until the needle is deflected the same number of degrees from the zero position as the angle of interception (minus lead appropriate to the rate of bearing change).
5. Turn inbound and continue with tracking procedures. If the needle is pointing in front of your intercept angle, you have not reached the bearing to be intercepted. If it points behind the intercept position, you have passed your bearing.

Interception of an outbound MB can be accomplished by the same procedures as for the inbound intercept, except that it is necessary to substitute the 180° position for the zero position on the needle.

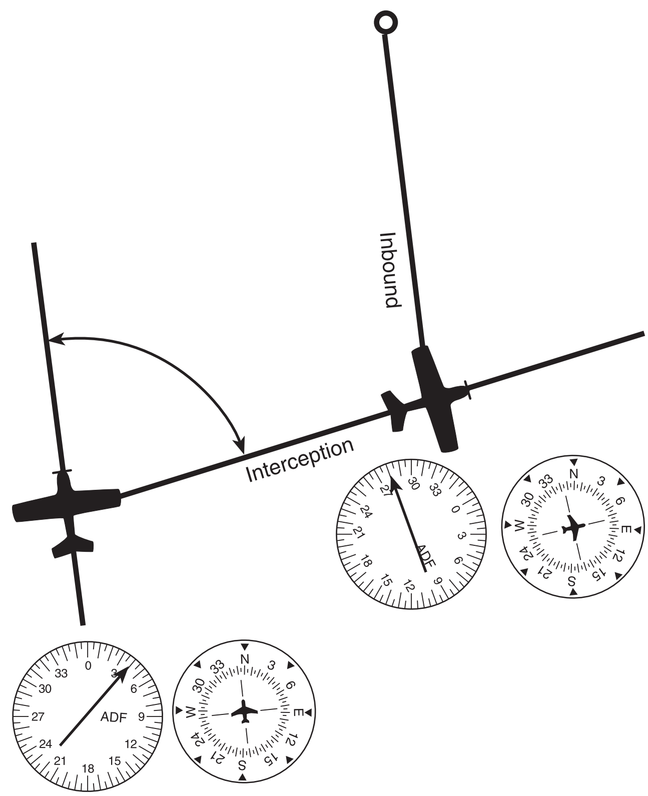


Figure 7-9. *Interception of bearing.*

Operational Errors of ADF

Some of the common pilot-induced errors associated with ADF navigation are listed below, to help you avoid making the same mistakes. The errors are:

1. Improper tuning and station identification. Many pilots have made the mistake of homing or tracking to the wrong station.

2. Positively identifying any malfunctions of the RMI slaving system or ignoring the warning flag.
3. Dependence on homing rather than proper tracking. This commonly results from sole reliance on the ADF indications, rather than correlating them with heading indications.
4. Poor orientation, due to failure to follow proper steps in orientation and tracking.
5. Careless interception angles, very likely to happen if you rush the initial orientation procedure.
6. Overshooting and undershooting predetermined MBs, often due to forgetting the course interception angles used.
7. Failure to maintain selected headings. Any heading change is accompanied by an ADF needle change. The instruments must be read in combination before any interpretation is made.
8. Failure to understand the limitations of the ADF and the factors that affect its use.
9. Overcontrolling track corrections close to the station (chasing the ADF needle), due to failure to understand or recognize station approach.
10. Failure to keep heading indicator set so it agrees with magnetic compass.

Very-High Frequency Omnidirectional Range (VOR)

Description

VOR is the primary navigational aid (NAVAID) used by civil aviation in the National Airspace System (NAS). The VOR ground station is oriented to magnetic north and transmits azimuth information to the aircraft, providing 360 courses TO or FROM the VOR station. When DME is installed with the VOR, it is referred to as a VOR/DME and provides both azimuth and distance information. When military tactical air navigation (TACAN) equipment is installed with the VOR, it is known as a VORTAC and provides both azimuth and distance information.

The courses oriented FROM the station are called **radials**. The VOR information received by an aircraft is not influenced by aircraft attitude or heading. [Figure 7-10] For example, aircraft A (heading 180°) is inbound on the 360° radial; after crossing the station, the aircraft is outbound on the 180° radial at A-1. Aircraft B is shown crossing the 225° radial. Similarly, at any point around the station, an aircraft can be located somewhere on a VOR radial.

Radials: The courses oriented FROM the station.

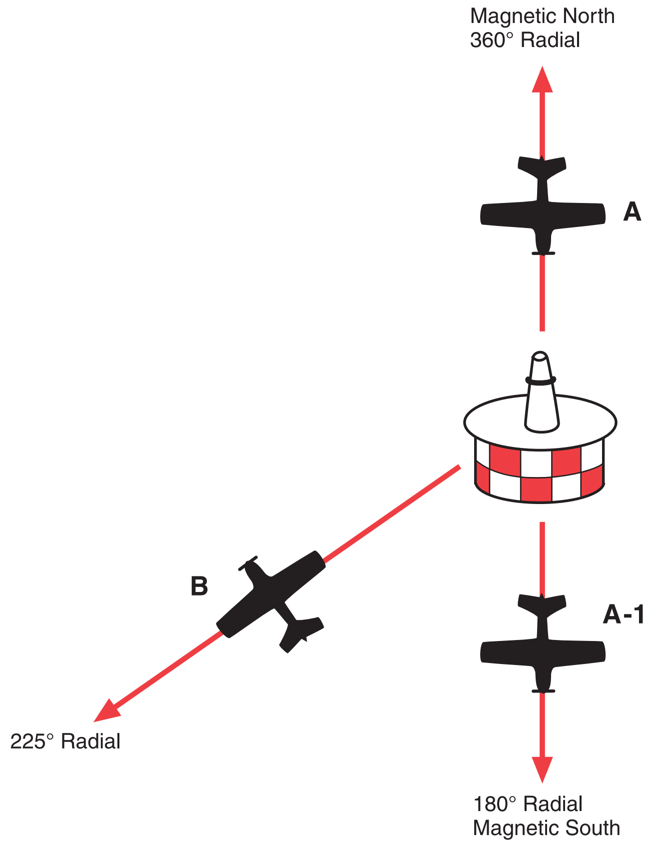


Figure 7-10. *VOR radials.*

The VOR receiver measures and presents information to indicate bearing TO or FROM the station. In addition to the navigation signals transmitted by the VOR, a Morse code signal is transmitted concurrently to identify the facility, as well as voice transmissions for communication and relay of weather and other information.

VORs are classified according to their operational uses. The standard VOR facility has a power output of approximately 200 watts, with a maximum usable range depending upon the aircraft altitude, class of facility, location and siting of the facility, terrain conditions within the usable area of the facility, and other factors. Above and beyond certain altitude and distance limits, signal interference from other VOR facilities and a weak signal make it unreliable. Coverage is typically at least 40 miles at normal minimum instrument flight rules (IFR) altitudes. VORs with accuracy problems in parts of their service volume are listed in Notices to Airmen (NOTAMs) and in the Airport/Facility Directory (A/FD) under the name of the NAVAID.

VOR Components

The ground equipment consists of a VOR ground station, which is a small, low building topped with a flat white disc, upon which are located the VOR antennas and a fiberglass cone-shaped tower. [Figure 7-11] The station includes an automatic monitoring system. The monitor automatically turns off defective equipment and turns on the standby transmitter. Generally, the accuracy of the signal from the ground station is within 1°.

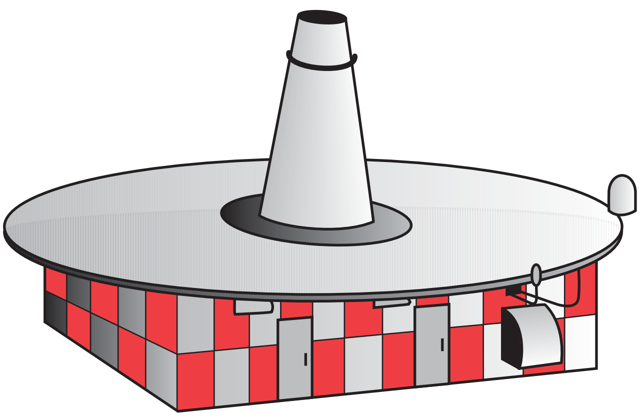


Figure 7-11. *VOR transmitter (ground station).*

VOR facilities are aurally identified by Morse code, or voice, or both. The VOR can be used for ground-to-air communication without interference with the navigation signal. VOR facilities operate within the 108.0 to 117.95 MHz frequency band and assignment between 108.0 and 112.0 MHz is in even-tenth decimals to preclude any conflict with ILS localizer frequency assignment, which uses the odd tenths in this range.

The airborne equipment includes an antenna, a receiver, and the indicator instrument. The receiver has a frequency knob to select any of the frequencies between 108.0 to 117.95 MHz. The ON/OFF/volume control turns on the navigation receiver and controls the audio volume. The volume has no effect on the operation of the receiver. You should listen to the station identifier before relying on the instrument for navigation.

VOR indicator instruments have at least the essential components shown in the instrument illustrated in figure 7-12.

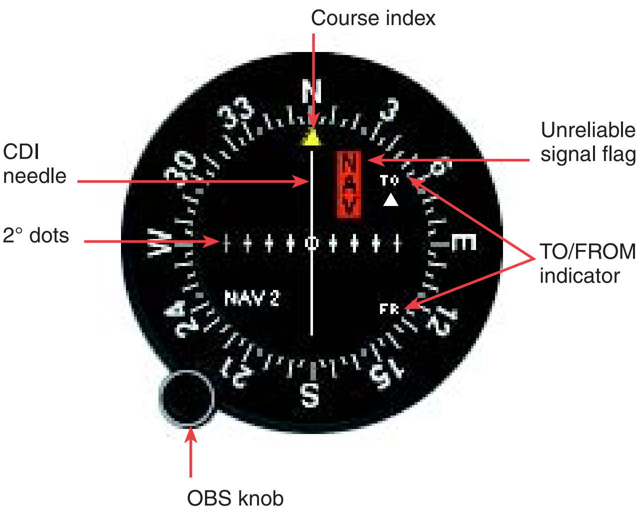


Figure 7-12. *The VOR indicator instrument.*

Omnibearing Selector (OBS). The desired course is selected by turning the OBS knob until the course is aligned with the course index mark or displayed in the course window.

Course deviation indicator (CDI). The deviation indicator is composed of an instrument face and a needle hinged to move laterally across the instrument face. The needle centers when the aircraft is on the selected radial or its reciprocal. Full needle deflection from the center position to either side of the dial indicates the aircraft is 10° or more off course, assuming normal needle sensitivity. The outer edge of the center circle is 2° off course; each dot signifies another 2°.

TO/FROM indicator. The TO/FROM indicator shows whether the selected course will take the aircraft TO or FROM the station. It does *not* indicate whether the aircraft is *heading* to or from the station.

Flags, or other signal strength indicators. The device that indicates a usable or an unreliable signal may be an "OFF" flag. It retracts from view when signal strength is sufficient for reliable instrument indications. Alternately, insufficient signal strength may be indicated by a blank or OFF in the TO/FROM window.

The indicator instrument may also be a **horizontal situation indicator (HSI)** which combines the heading indicator and CDI. [Figure 7-13] The combination of navigation information from VOR/Localizer (LOC) or from LORAN or GPS, with aircraft heading information provides a visual picture of the aircraft's location and direction. This decreases pilot workload especially with tasks such as course intercepts, flying a back-course approach, or holding pattern entry. (*See* Chapter 3, for operational characteristics.)

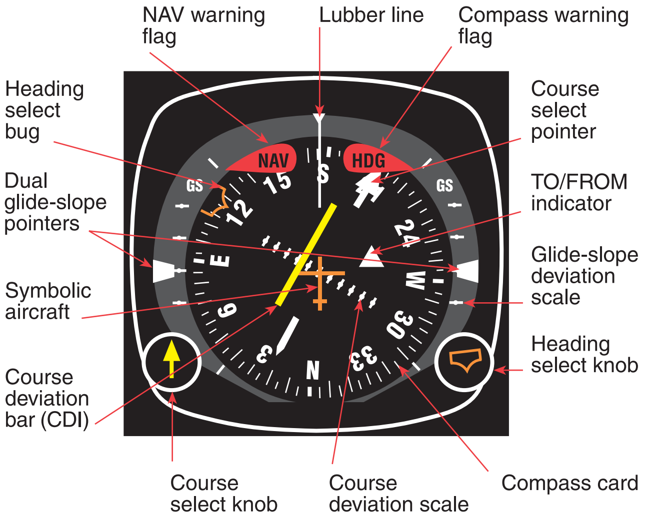


Figure 7-13. *Horizontal situation indicator (HSI).*

Horizontal situation indicator (HSI): A flight navigation instrument that combines the heading indicator with a CDI, in order to provide the pilot with better situational awareness of location with respect to the courseline.

Function of VOR

Orientation

The VOR does not account for the aircraft heading, it only relays the aircraft direction from the station and will have the same indications regardless of which way the nose is pointing. Tune the VOR receiver to the appropriate frequency of the selected VOR ground station, turn up the audio volume, and identify the station's signal audibly. Then rotate the OBS to center the CDI needle, and read the course under or over the index.

In figure 7-12, 360° TO is the course indicated, while in figure 7-14, 180° TO is the course. The latter indicates that the aircraft (which may be heading in any direction) is, at this moment, located at any point on the 360° radial (line from the station) except directly over the station or very close to it, as in points I to S in figure 7-14. The CDI will deviate from side to side as the aircraft passes over or nearly over the station because of the volume of space above the station where the **zone of confusion** exists. This zone of confusion is caused by lack of adequate signal directly above the station due to the radiation pattern of the station's antenna, and because the resultant of the opposing reference and variable signals is small and constantly changing.

The CDI in figure 7-14 indicates 180°, meaning that the aircraft is on the 180° or the 360° radial of the station. The TO/FROM indicator resolves the ambiguity. If the TO indicator is showing, then it is 180° TO the station. The FROM indication indicates the radial of the station the aircraft is presently on. Movement of the CDI from center, if it occurs at a relatively constant rate, indicates the aircraft is moving or drifting off the 180°/360° line. If the movement is rapid or fluctuating, this is an indication of impending station passage (the aircraft is near the station). To determine the aircraft's position relative to the station, rotate the OBS until FROM appears in the window, then center the CDI needle. The index indicates the VOR radial where the aircraft is located. The inbound (to the station) course is the reciprocal of the radial.

If you set the VOR to the reciprocal of your course, the CDI will reflect **reverse sensing**. To correct for needle deflection, you will need to fly away from the needle. To avoid this reverse sensing situation, set the VOR to agree with your intended course.

Zone of confusion: Volume of space above the station where a lack of adequate navigation signal directly above the VOR station causes the needle to deviate.

Reverse sensing: When the VOR needle indicates the reverse of normal operation. This occurs when the aircraft is headed toward the station with a FROM indication or when the aircraft is headed away from the station with a TO indication.

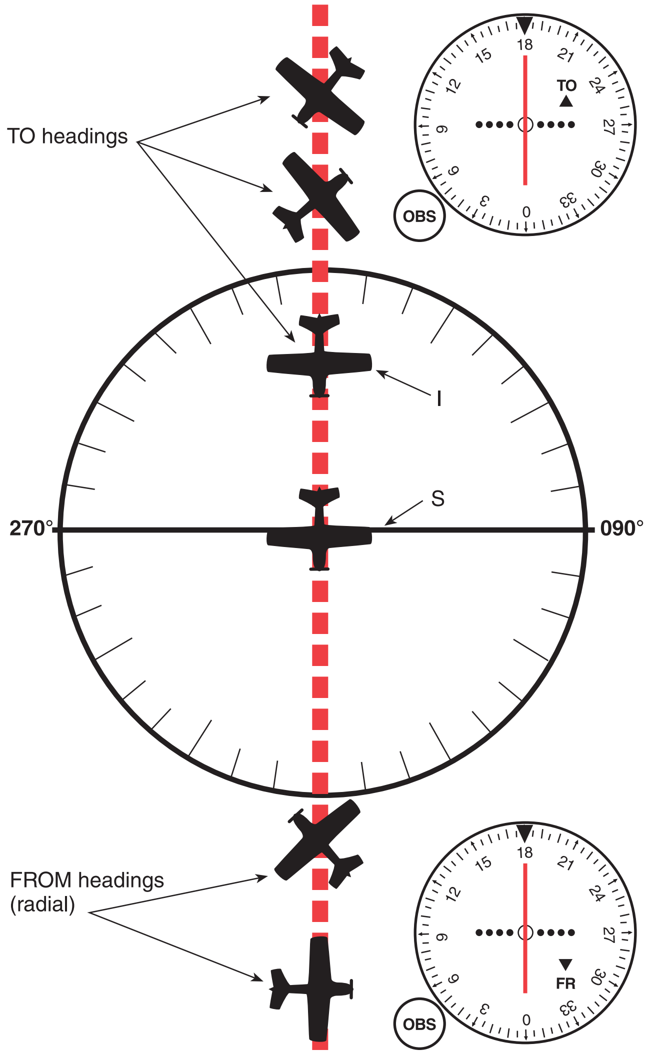


Figure 7-14. *CDI interpretation.*

A single NAVAID will only allow you to determine your position relative to a radial. You need to cross-reference the indications from a second NAVAID in order to narrow your position down to an exact location on this radial.

Tracking TO and FROM the Station

To track to the station, rotate the OBS until TO appears, then center the CDI. Fly the course indicated by the index. If the CDI moves off center to the left, follow the needle by correcting course to the left, beginning with a 20° correction. When you are flying the course indicated on the index, a left deflection of the needle indicates a crosswind component from the left. If the amount of correction brings the needle back to center, decrease the left course correction by half. If the CDI moves left or right now, it should do so much slower, and you can make a smaller heading correction for the next iteration.

Keeping the CDI centered will take the aircraft to the station. To track to the station, the OBS value at the index is not changed. To home to the station, the CDI needle is periodically centered, and the new course under the index is used for the aircraft heading. Homing will follow a circuitous route to the station, just as with ADF homing.

To track FROM the station on a VOR radial, you should first orient the aircraft's location with respect to the station and the desired outbound track by centering the CDI needle with a FROM indication. The track is intercepted by either flying over the station or establishing an intercept heading. The magnetic course of the desired radial is entered under the index using the OBS and the intercept heading held until the CDI centers. Then the procedure for tracking to the station is used to fly outbound on the specified radial.

Course Interception

If your desired course is not the one you are flying, you must first orient yourself with respect to the VOR station and the course to be flown, and then establish an intercept heading. The following steps may be used to intercept a predetermined course, either inbound or outbound. Steps 1-3 may be omitted if you turn directly to intercept the course without initially turning to parallel the desired course.

1. Turn to a heading to parallel the desired course, in the same direction as the course to be flown.
2. Determine the difference between the radial to be intercepted and the radial on which you are located.
3. Double the difference to determine the interception angle, which will not be less than 20° nor greater than 90°.
4. Rotate the OBS to the desired radial or inbound course.
5. Turn to the interception heading.
6. Hold this heading constant until the CDI centers, which indicates the aircraft is on course. (With practice in judging the varying rates of closure with the course centerline, you learn to lead the turn to prevent overshooting the course.)
7. Turn to the MH corresponding to the selected course, and follow tracking procedures inbound or outbound.

Course interception is illustrated in figure 7-15.

To intercept a course of 025°, inbound of VOR A:

1. Present position, inbound on 160 radial.
2. Turn right to parallel inbound course. 025° – 180° = 205°, 205 – 160 = 45° (double 45 for interception angle of 90°). Turn to 295° (205° + 90°).
3. Maintain heading of 295° until 205 radial is intercepted (OBS 025, needle centered).
4. Track inbound on 205 radial.

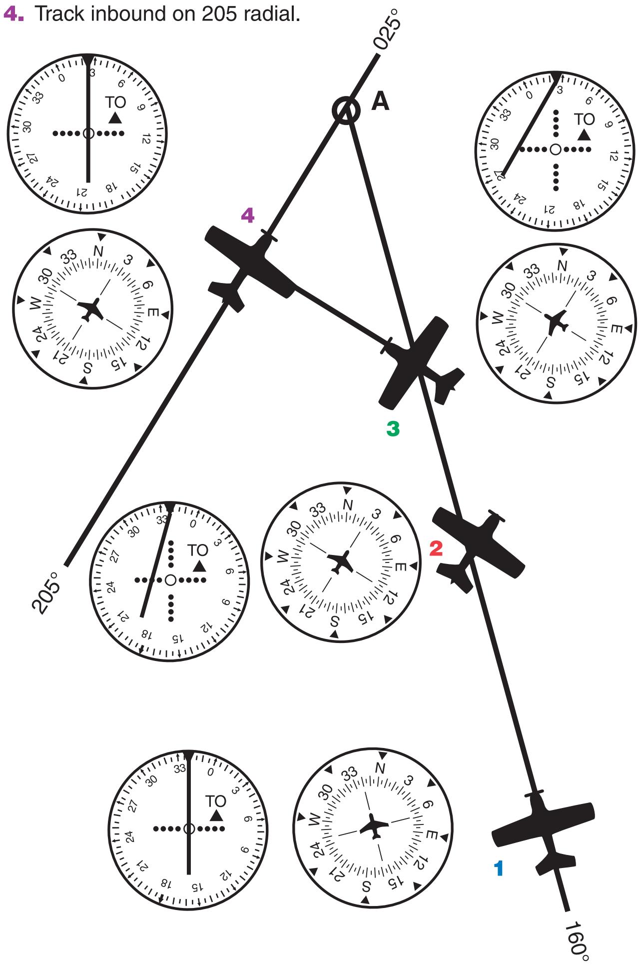


Figure 7-15. *Course interception (VOR).*

VOR Operational Errors

Typical pilot-induced errors include:

1. Careless tuning and identification of station.
2. Failure to check receiver for accuracy/sensitivity.
3. Turning in the wrong direction during an orientation. This error is common until you visualize *position* rather than *heading*.
4. Failure to check the ambiguity (TO/FROM) indicator, particularly during course reversals, resulting in reverse sensing and corrections in the wrong direction.
5. Failure to parallel the desired radial on a track interception problem. Without this step, orientation to the desired radial can be confusing. Since you think in left/right terms, aligning your aircraft position to the radial/course is essential.
6. Overshooting and undershooting radials on interception problems.
7. Overcontrolling corrections during tracking, especially close to the station.
8. Misinterpretation of station passage. On VOR receivers equipped without an ON/OFF flag, a voice transmission on the combined communication and navigation radio (NAV/COM) in use for VOR may cause the same TO/FROM fluctuations on the ambiguity meter as shown during station passage. Read the whole receiver—TO/FROM, CDI, and OBS—before you make a decision. Do not utilize a VOR reading observed while transmitting.
9. Chasing the CDI, resulting in homing instead of tracking. Careless heading control and failure to bracket wind corrections makes this error common.

VOR Accuracy

The effectiveness of the VOR depends upon proper use and adjustment of both ground and airborne equipment.

The accuracy of course alignment of the VOR is generally plus or minus 1°. On some VORs, minor course roughness may be observed, evidenced by course needle or brief flag alarm. At a few stations, usually in mountainous terrain, the pilot may occasionally observe a brief course needle oscillation, similar to the indication of "approaching station." Pilots flying over unfamiliar routes are cautioned to be on the alert for these vagaries, and in particular, to use the TO/FROM indicator to determine positive station passage.

Certain propeller revolutions per minute (RPM) settings or helicopter rotor speeds can cause the VOR CDI to fluctuate as much as plus or minus 6°. Slight changes to the RPM setting will normally smooth out this roughness. Pilots are urged to check for this modulation phenomenon prior to reporting a VOR station or aircraft equipment for unsatisfactory operation.

VOR Receiver Accuracy Check

VOR system course sensitivity may be checked by noting the number of degrees of change as you rotate the OBS to move the CDI from center to the last dot on either side. The course selected should not exceed 10° or 12° either side. In addition, Title 14 of the Code of Federal Regulations

(14 CFR) part 91 provides for certain VOR equipment accuracy checks, and an appropriate endorsement, within 30 days prior to flight under IFR. To comply with this requirement and to ensure satisfactory operation of the airborne system, use the following means for checking VOR receiver accuracy:

1. VOT or a radiated test signal from an appropriately rated radio repair station.
2. Certified checkpoints on the airport surface.
3. Certified airborne checkpoints.

VOT

The Federal Aviation Administration (FAA) **VOR test facility (VOT)** transmits a test signal which provides users a convenient means to determine the operational status and accuracy of a VOR receiver while on the ground where a VOT is located. Locations of VOTs are published in the A/FD. Two means of identification are used. One is a series of dots and the other is a continuous tone. Information concerning an individual test signal can be obtained from the local flight service station (FSS.) The airborne use of VOT is permitted; however, its use is strictly limited to those areas/altitudes specifically authorized in the A/FD or appropriate supplement.

To use the VOT service, tune in the VOT frequency 108.0 MHz on the VOR receiver. With the CDI centered, the OBS should read 0° with the TO/FROM indication showing FROM or the OBS should read 180° with the TO/FROM indication showing TO. Should the VOR receiver operate an RMI, it will indicate 180° on any OBS setting.

A radiated VOT from an appropriately rated radio repair station serves the same purpose as an FAA VOT signal, and the check is made in much the same manner as a VOT with some differences.

The frequency normally approved by the Federal Communications Commission (FCC) is 108.0 MHz; however, repair stations are not permitted to radiate the VOR test signal continuously. The owner or operator of the aircraft must make arrangements with the repair station to have the test signal transmitted. A representative of the repair station must make an entry into the aircraft logbook or other permanent record certifying to the radial accuracy and the date of transmission.

VOR test facility (VOT): A ground facility which emits a test signal to check VOR receiver accuracy. Some VOTs are available to the user while airborne, while others are limited to ground use only.

Certified Checkpoints

Airborne and ground checkpoints consist of certified radials that should be received at specific points on the airport surface or over specific landmarks while airborne in the immediate vicinity of the airport. Locations of these checkpoints are published in the A/FD.

Should an error in excess of plus or minus 4° be indicated through use of a ground check, or plus or minus 6° using the airborne check, IFR flight shall not be attempted without first correcting the source of the error. No correction other than the correction card figures supplied by the manufacturer should be applied in making these VOR receiver checks.

If a dual system VOR (units independent of each other except for the antenna) is installed in the aircraft, one system may be checked against the other. Turn both systems to the same VOR ground facility and note the indicated bearing to that station. The maximum permissible variations between the two indicated bearings is 4°.

Distance Measuring Equipment (DME)

Description

When used in conjunction with the VOR system, DME makes it possible for pilots to determine an accurate geographic position of the aircraft, including the bearing and distance TO or FROM the station. The aircraft DME transmits interrogating radio frequency (RF) pulses, which are received by the DME antenna at the ground facility. The signal triggers ground receiver equipment to respond back to the interrogating aircraft. The airborne DME equipment measures the elapsed time between the interrogation signal sent by the aircraft and reception of the reply pulses from the ground station. This time measurement is converted into nautical miles (NMs) distance from the station.

Some DME receivers provide a groundspeed in knots by monitoring the rate of change of the aircraft's position relative to the ground station. Groundspeed values are only accurate when tracking directly to or from the station.

DME Components

VOR/DME, VORTAC, ILS/DME, and LOC/DME navigation facilities established by the FAA provide course and distance information from collocated components under a frequency pairing plan. DME operates on frequencies in the UHF spectrum between 962 MHz and 1213 MHz. Aircraft receiving equipment which provides for automatic DME selection assures reception of azimuth and distance information from a common source when designated VOR/DME, VORTAC, ILS/DME, and LOC/DME are selected. Some aircraft have separate VOR and DME receivers each of which must be tuned to the appropriate navigation facility.

The airborne equipment includes an antenna and a receiver.

The pilot-controllable features of the DME receiver include:

Channel (frequency) selector. Many DMEs are channeled by an associated VHF radio, or there may be a selector switch so you can select which VHF radio is channeling the DME. For the DMEs that have their own frequency selector, you use the frequency of the associated VOR/DME or VORTAC station.

On/Off/Volume switch. The DME identifier will be heard as a Morse code identifier with a tone somewhat higher than that of the associated VOR or LOC. It will be heard once for every three or four times the VOR or LOC identifier is heard. If only one identifier is heard about every 30 seconds, the DME is functional, but the associated VOR or LOC is not.

Mode switch. The mode switch selects between distance (DIST) or distance in NMs, groundspeed and time to station. There may also be one or more HOLD functions which permit the DME to stay channeled to the station that was selected before the switch was placed in the hold position. This is useful when you make an ILS approach at a facility that has no colocated DME, but there is a VOR/DME nearby.

Altitude. Some DMEs correct for slant-range error.

Function of DME

A DME is used for determining the distance from a ground DME transmitter. Compared to other VHF/UHF NAVAIDs, a DME is very accurate. The distance information can be used to determine the aircraft position or flying a track that is a constant distance from the station. This is referred to as a **DME arc**.

DME Arc

There are many instrument approach procedures (IAPs) that incorporate DME arcs. The procedures and techniques given here for intercepting and maintaining such arcs are applicable to any facility that provides DME information. Such a facility may or may not be colocated with the facility that provides final approach guidance.

DME arc: Flying a track that is a constant distance from the station.

As an example of flying a DME arc, refer to figure 7-16 and follow these steps:

1. Track inbound on the OKT 325° radial, frequently checking the DME mileage readout.
2. A .5 NM lead is satisfactory for groundspeeds of 150 knots or less; start the turn to the arc at 10.5 miles. At higher groundspeeds, use a proportionately greater lead.
3. Continue the turn for approximately 90°. The roll-out heading will be 055° in no-wind conditions.
4. During the last part of the intercepting turn, monitor the DME closely. If the arc is being overshot (more than 1.0 NM), continue through the originally-planned roll-out heading. If the arc is being undershot, roll out of the turn early.

The procedure for intercepting the 10 DME when outbound is basically the same, the lead point being 10 NM minus .5 NM, or 9.5 NM.

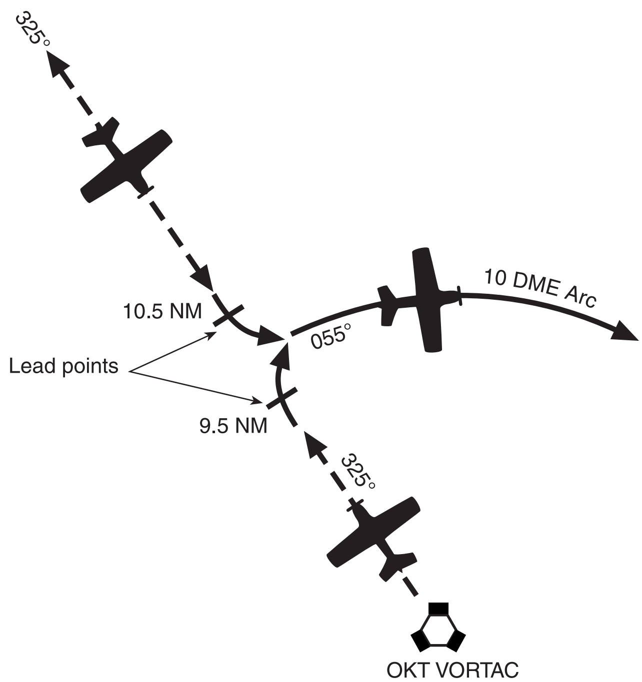


Figure 7-16. *DME arc interception.*

When flying a DME arc with wind, it is important that you keep a continuous mental picture of your position relative to the facility. Since the wind-drift correction angle is constantly changing throughout the arc, wind orientation is important. In some cases, wind can be used in returning to the desired track. High airspeeds require more pilot attention because of the higher rate of deviation and correction.

Maintaining the arc is simplified by keeping slightly inside the curve; thus, the arc is turning toward the aircraft and interception may be accomplished by holding a straight course. If you are outside the curve, the arc is "turning away" and a greater correction is required.

To fly the arc using the VOR CDI, center the CDI needle upon completion of the 90° turn to intercept the arc. The aircraft's heading will be found very near the left or right side (270° or 90° reference points) of the instrument. The readings at that side location on the instrument will give primary heading information while on the arc. Adjust the aircraft heading to compensate for wind and to correct for distance to maintain the correct arc distance. Re-center the CDI and note the new primary heading indicated whenever the CDI gets 2°–4° from center.

With an RMI, in a no-wind condition, you should theoretically be able to fly an exact circle around the facility by maintaining an RB of 90° or 270°. In actual practice, a series of short legs are flown. To maintain the arc in figure 7-17, proceed as follows:

1. With the RMI bearing pointer on the wingtip reference (90° or 270° position) and the aircraft at the desired DME range, maintain a constant heading and allow the bearing pointer to move 5° to 10° behind the wingtip. This will cause the range to increase slightly.
2. Turn toward the facility to place the bearing pointer 5°–10° ahead of the wingtip reference, then maintain heading until the bearing pointer is again behind the wingtip. Continue this procedure to maintain the approximate arc.
3. If a crosswind is drifting you away from the facility, turn the aircraft until the bearing pointer is ahead of the wingtip reference. If a crosswind is drifting you toward the facility, turn until the bearing is behind the wingtip.
4. As a guide in making range corrections, change the RB 10°–20° for each half-mile deviation from the desired arc. For example, in no-wind conditions, if you are 1/2 to 1 mile outside the arc and the bearing pointer is on the wingtip reference, turn the aircraft 20° toward the facility to return to the arc.

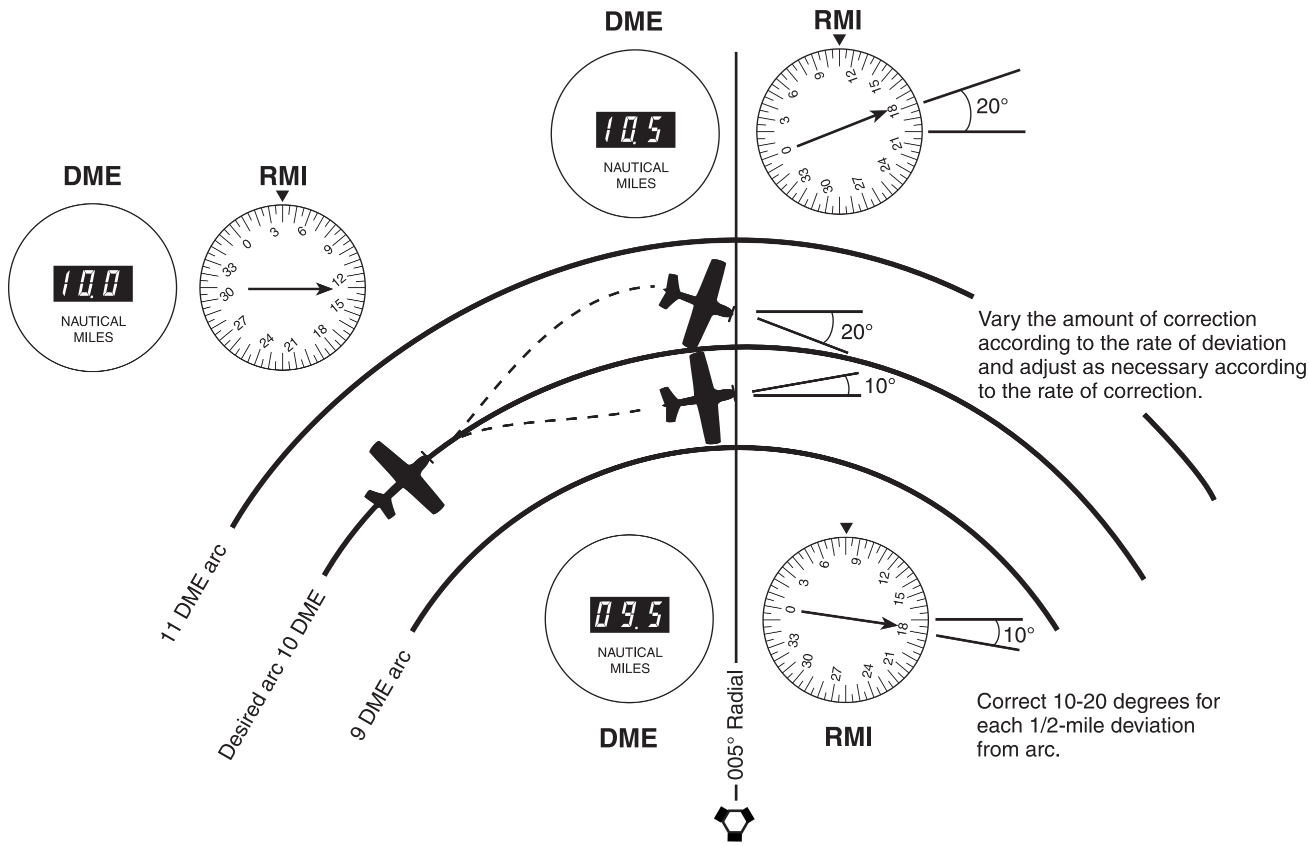


Figure 7-17. *Using DME and RMI to maintain arc.*

Without an RMI, orientation is more difficult since you do not have a direct azimuth reference. However, the procedure can be flown using the OBS and CDI for azimuth information and the DME for arc distance.

Intercepting Lead Radials

A **lead radial** is the radial at which the turn from the arc to the inbound course is started. When intercepting a radial from a DME arc, the lead will vary with arc radius and groundspeed. For the average general aviation aircraft, flying arcs such as those depicted on most approach charts at speeds of 150 knots or less, the lead will be under 5°. There is no difference between intercepting a radial from an arc and intercepting it from a straight course.

With an RMI, the rate of bearing movement should be monitored closely while flying the arc. Set the course of the radial to be intercepted as soon as possible and determine the approximate lead. Upon reaching this point, start the intercepting turn. Without an RMI, the technique for radial interception is the same except for azimuth information which is available only from the OBS and CDI.

The technique for intercepting a localizer from a DME arc is similar to intercepting a radial. At the depicted lead radial (LR 070° or LR 084° in figure 7-18), a pilot having a single VOR/LOC receiver should set it to the localizer frequency. If the pilot has dual VOR/LOC receivers, one unit may be used to provide azimuth information and the other set to the localizer frequency. Since these lead radials provide 7° of lead, a half-standard-rate turn should be used until the LOC needle starts to move toward center.

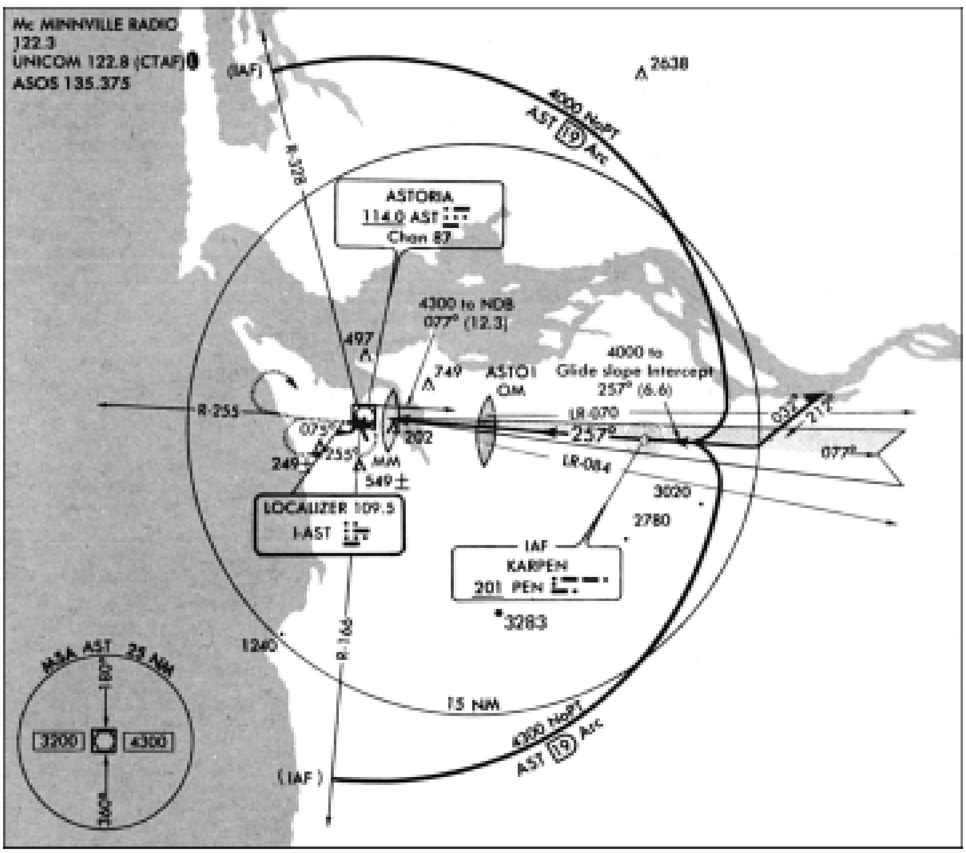


Figure 7-18. *Localizer interception from DME arc.*

Lead radial: The radial at which the turn from the arc to the inbound course is started.

DME Errors

DME/DME fixes (a location based on two DME lines of position from two DME stations) provide a more accurate aircraft location than using a VOR and a DME fix.

DME signals are line-of-sight; the mileage readout is the straight line distance from the aircraft to the DME ground facility and is commonly referred to as slant range distance. Slant range refers to the straight line distance from the aircraft antenna to the ground station, which differs somewhat from the distance from the station to the point on the ground beneath the aircraft. This error is smallest at low altitude and long range. It is greatest when the aircraft is over the ground facility, at which time the DME receiver will display altitude (in NM) above the facility. Slant-range error is negligible if the aircraft is 1 mile or more from the ground facility for each 1,000 feet of altitude above the elevation of the facility.

Area Navigation (RNAV)

Description

Area navigation (RNAV) equipment includes VOR/DME, LORAN, GPS, and inertial navigation systems (INS). RNAV equipment is capable of computing the aircraft position, actual track, groundspeed, and then presenting meaningful information to the pilot. This information may be in the form of distance, crosstrack error, and time estimates relative to the selected track or **waypoint**. In addition, the RNAV equipment installations must be approved for use under IFR. The Pilot's Operating Handbook/Airplane Flight Manual (POH/AFM) should always be consulted to determine what equipment is installed, the operations that are approved, and the details of how to use the equipment. Some aircraft may have equipment that allows input from more than one RNAV source thereby providing a very accurate and reliable navigation source.

VOR/DME RNAV

VOR RNAV is based on information generated by the present VORTAC or VOR/DME systems to create a waypoint using an airborne computer. As shown in figure 7-19, the value of side A is the measured DME distance to the VOR/DME. Side B, the distance from the VOR/DME to the waypoint, angle 1 (VOR radial or the bearing from the VORTAC to the waypoint), are values set in the cockpit control. The bearing from the VOR/DME to the aircraft, angle 2, is measured by the VOR receiver. The airborne computer continuously compares angles 1 and 2 and determines angle 3 and side C, which is the distance in NMs and magnetic course from the aircraft to the waypoint. This is presented as guidance information on the cockpit display.

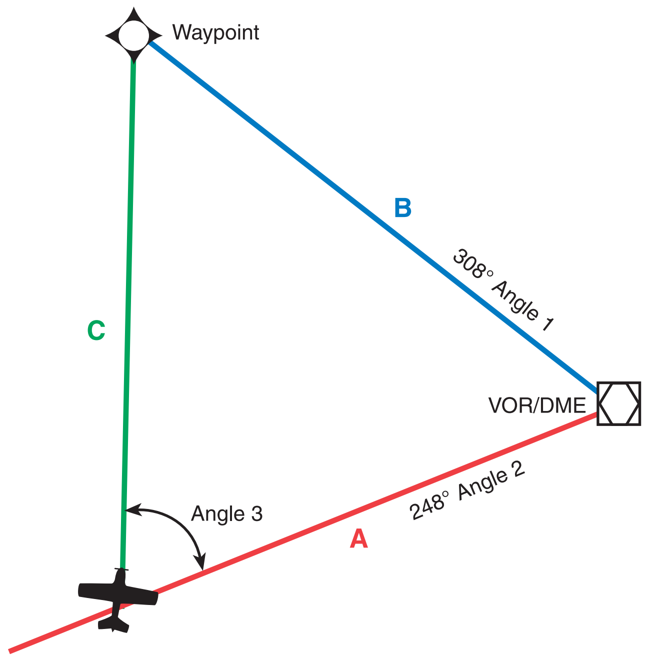


Figure 7-19. *RNAV computation.*

VOR/DME RNAV Components

Although RNAV cockpit instrument displays vary among manufacturers, most are connected to the aircraft CDI with a switch or knob to select VOR or RNAV guidance. There is usually a light or indicator to inform the pilot whether VOR or RNAV is selected. [Figure 7-20] The display includes the waypoint, frequency, mode in use, waypoint radial and distance, DME distance, groundspeed, and time to station. Most VOR/DME RNAV systems have the following airborne controls:

1. Off/On/Volume control to select the frequency of the VOR/DME station to be used.

Waypoint: A designated geographical location used for route definition or progress-reporting purposes and defined relative to a VOR/DME station or in terms of latitude/longitude coordinates.

2. MODE select switch used to select VOR/DME mode, with:
   a. Angular course width deviation (standard VOR operation); or
   b. Linear crosstrack deviation as standard (±5 NM full scale CDI).
3. RNAV mode, with direct to waypoint with linear crosstrack deviation of ±5 NM.
4. RNAV/APPR (approach mode) with linear deviation of ±1.25 NM as full scale CDI deflection.
5. Waypoint select control. Some units allow the storage of more than one waypoint; this control allows selection of any waypoint in storage.
6. Data input controls. These controls allow user input of waypoint number or ident, VOR or LOC frequency, waypoint radial and distance.

While DME groundspeed readout is accurate only when tracking directly to or from the station in VOR/DME mode, in RNAV mode the DME groundspeed readout is accurate on any track.

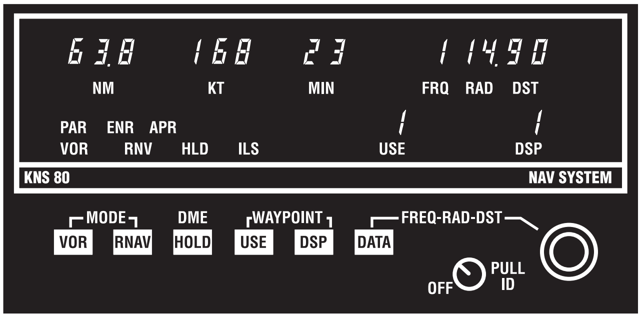


Figure 7-20. *Typical RNAV display.*

Function of VOR/DME RNAV

The advantages of the VOR/DME RNAV system stem from the ability of the airborne computer to locate a waypoint wherever it is convenient, as long as the aircraft is within reception range of both a nearby VOR and DME facility. A series of these waypoints make up an RNAV route. In addition to the published routes, a random RNAV route may be flown under IFR if it is approved by air traffic control (ATC). RNAV DPs and standard terminal arrival routes (STARs) are contained in the DP and STAR booklets.

VOR/DME RNAV approach procedure charts are also available. Note in the VOR/DME RNAV chart excerpt shown in figure 7-21 that the waypoint identification boxes contain the following information: waypoint name, coordinates, frequency, identifier, radial distance (facility to waypoint), and reference facility elevation. The initial approach fix (IAF), final approach fix (FAF), and missed approach point (MAP) are labeled.

To fly either a route or to execute an approach under IFR, the RNAV equipment installed in the aircraft must be approved for the appropriate IFR operations.

In Vertical Nav mode, vertical, as well as horizontal guidance is provided in some installations. A waypoint is selected at a point where the descent begins, and another waypoint is selected where the descent ends. The RNAV equipment computes the rate of descent relative to the groundspeed, and on some installations, displays vertical guidance information on the glide-slope indicator. When using this type of equipment during an instrument approach, the pilot must keep in mind the vertical guidance information provided is *not* part of the nonprecision approach. Published nonprecision approach altitudes must be observed and complied with, unless otherwise directed by ATC.

To fly to a waypoint using RNAV, observe the following procedure [Figure 7-22]:

1. Select the VOR/DME frequency.
2. Select the RNAV mode.
3. Select the radial of the VOR that passes through the waypoint (225°).
4. Select the distance from the DME to the waypoint is selected (12 NM).
5. Check and confirm all inputs, and the CDI needle is centered with the TO indicator showing.
6. Maneuver the aircraft to fly the indicated heading ± wind correction to keep the CDI needle centered.
7. The CDI needle will indicate distance off course of 1 NM per dot; the DME readout will indicate distance (NM) from the waypoint; the groundspeed will read closing speed (knots) to the waypoint; and the time to station (TTS) will read time to the waypoint.

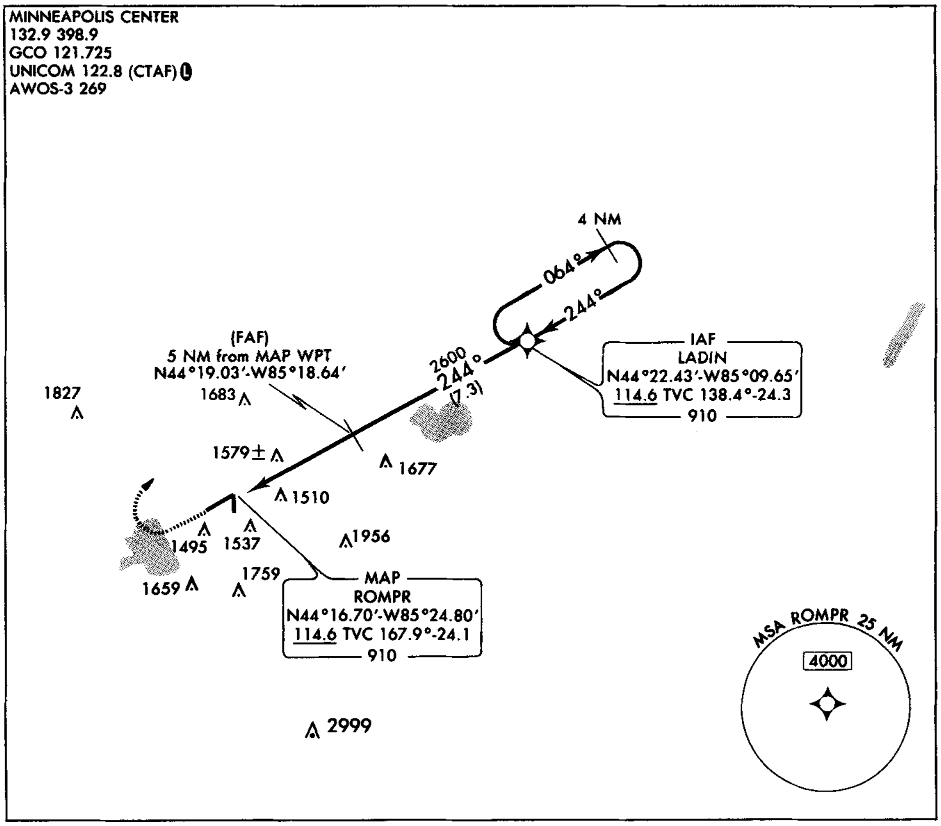


Figure 7-21. *VOR/DME RNAV Rwy 25 approach (excerpt).*

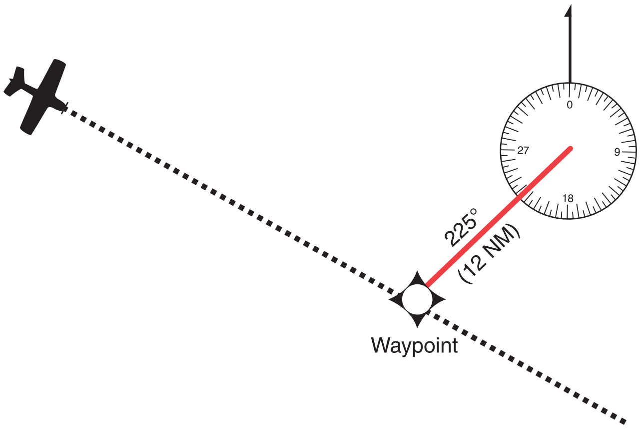


Figure 7-22. *Aircraft/VORTAC/waypoint relationship.*

VOR/DME RNAV Errors

The limitation of this system is the reception volume. Published approaches have been tested to ensure this is not a problem. Descents/approaches to airports distant from the VOR/DME facility may not be possible because during the approach, the aircraft may descend below the reception altitude of the facility at that distance.

Long Range Navigation (LORAN)

LORAN uses a network of land-based transmitters to provide an accurate long range navigation system. The FAA and the United States (U.S.) Coast Guard (USCG) arranged the stations into chains. The signals from these stations are a carefully structured sequence of brief RF pulses centered at 100 kHz. At that frequency, signals travel considerable distances as ground waves, from which accurate navigation information is available. The airborne receiver monitors all of the stations within the selected chain, then measures the arrival time difference (TD) between the signals. All of the points having the same TD from a station pair create a line of position (LOP). The aircraft position is determined at the intersection of two or more LOPs. Then the computer converts the known location to latitude and longitude coordinates. While continually computing latitude/longitude fixes, the computer is able to determine and display:

1. Track over the ground since last computation;
2. Groundspeed by dividing distance covered since last computation by the time since last computation (and averaging several of these);
3. Distance to destination;
4. Destination time of arrival; and
5. Crosstrack error.

The *Aeronautical Information Manual* (AIM) provides a detailed explanation of how LORAN works. LORAN is a very accurate navigation system if adequate signals are received. There are two types of accuracy that must be addressed in any discussion of LORAN accuracy.

Repeatable accuracy is the accuracy measured when a user notes the LORAN position, moves away from that location, then uses the LORAN to return to that initial LORAN position. Distance from that initial position is the error. Propagation and terrain errors will be essentially the same as when the first position was taken, so those errors are factored out by using the initial position. Typical repeatable accuracy for LORAN can be as good as 0.01 NM, or 60 feet, if the second position is determined during the day and within a short period of time (a few days).

Absolute accuracy refers to the ability to determine present position in space independently, and is most often used by pilots. When the LORAN receiver is turned on and position is determined, absolute accuracy applies. Typical LORAN absolute accuracy will vary from about 0.1 NM to as much as 2.5 NM depending on distance from the station, geometry of the TD LOP crossing angles, terrain and environmental conditions, signal-to-noise ratio (signal strength), and some design choices made by the receiver manufacturer.

LORAN Components

The LORAN receiver incorporates a radio receiver, signal processor, navigation computer, control/display, and antenna. When turned on, the receivers go through an initialization or warm-up period, then inform the user they are ready to be programmed. LORAN receivers vary widely in their appearance, how they are programmed by the user, and how they display navigation information. Therefore, it is necessary to become familiar with the unit, including how to program it, and how to interpret output from it. The LORAN operating manual should be in the aircraft at all times and available to the pilot. IFR-approved LORAN units require that the manual be aboard and that the pilot is familiar with the unit's functions, *before* flight.

Function of LORAN

After initialization, you select for the present location waypoint (the airport), and select GO TO in order to determine if the LORAN is functioning properly. Proper operation is indicated by a low distance reading (0 to 0.5 NM). The simplest mode of navigation is referred to as GO TO: you select a waypoint from one of the databases and choose the GO TO mode. Before use in flight, you should verify that the latitude and longitude of the chosen waypoint is correct by reference to another approved information source. An updatable LORAN database that supports the appropriate operations (e.g., en route, terminal, and instrument approaches), is required when operating under IFR.

In addition to displaying bearing, distance, time to the waypoint, and track and speed over the ground, the LORAN receiver may have other features such as flight planning (waypoint sequential storage), emergency location of several nearest airports, vertical navigation capabilities, and more.

LORAN Errors

System Errors

LORAN is subject to interference from many external sources, which can cause distortion of, or interference with LORAN signals. LORAN receiver manufacturers install "notch filters" to reduce or eliminate interference. Proximity to 60 Hz alternating current power lines, static discharge, precipitation static, electrical noise from generators, alternators, strobes, and other onboard electronics may decrease the signal-to-noise ratio to the point where the LORAN receiver's performance is degraded.

Proper installation of the antenna, good electrical bonding, and an effective static discharge system are the minimum requirements for LORAN receiver operation. Most receivers have internal tests that verify the timing alignment of the receiver clock with the LORAN pulse, and measure and display signal-to-noise ratio. A signal will be activated to alert the pilot if any of the parameters for reliable navigation are exceeded on LORAN sets certified for IFR operations.

LORAN is most accurate when the signal travels over sea water during the day, and least accurate when the signal comes over land and large bodies of fresh water or ice at night; furthermore, the accuracy degrades as distance from the station increases. However, LORAN accuracy is generally better than VOR accuracy.

Operational Errors

Some of the typical pilot-induced errors of LORAN operation are:

1. Use of a nonapproved LORAN receiver for IFR operations. The pilot should check the aircraft's POH/AFM LORAN supplement to be certain the unit's functions are well understood (this supplement must be present in the aircraft for approved IFR operations). There should be a copy of FAA Form 337, Major Repair and Alteration, present in the aircraft's records, showing approval (for use of this model LORAN for IFR operations in this aircraft).

2. Failure to double-check the latitude/longitude values for a waypoint to be used. Whether the waypoint was accessed from the airport, NDB, VOR, or intersection database, the values of latitude and longitude should still be checked against the values in the A/FD or other approved source. If the waypoint data is entered in the user database, its accuracy must be checked before use.
3. Attempting to use LORAN information with degraded signals.

Global Positioning System (GPS)

The Department of Defense (DOD) developed and deployed **GPS** as a space-based positioning, velocity, and time system. The DOD is responsible for the operation the GPS satellite constellation and constantly monitors the satellites to ensure proper operation. The GPS system permits Earth-centered coordinates to be determined and provides aircraft position referenced to the DOD World Geodetic System of 1984 (WGS-84). Satellite navigation systems are unaffected by weather and provide global navigation coverage that fully meets the civil requirements for use as the primary means of navigation in oceanic airspace and certain remote areas. Properly certified GPS equipment may be used as a supplemental means of IFR navigation for domestic en route, terminal operations, and certain IAPs. Navigational values, such as distance and bearing to a waypoint and groundspeed, are computed from the aircraft's current position (latitude and longitude) and the location of the next waypoint. Course guidance is provided as a linear deviation from the desired track of a Great Circle route between defined waypoints.

GPS may not be approved for IFR use in other countries. Prior to its use, pilots should ensure that GPS is authorized by the appropriate countries.

GPS Components

GPS consists of three distinct functional elements: space, control, and user.

The *space* element consists of 24 Navstar satellites. This group of satellites is called a constellation. The satellites are in six orbital planes (with four in each plane) at about 11,000 miles above the Earth. At least five satellites are in view at all times. The GPS constellation broadcasts a pseudo-random code timing signal and data message that the aircraft equipment processes to obtain satellite position and status data. By knowing the precise location of each satellite and precisely matching timing with the atomic clocks on the satellites, the aircraft receiver/processor can accurately measure the time each signal takes to arrive at the receiver and, therefore, determine aircraft position.

The *control* element consists of a network of ground-based GPS monitoring and control stations that ensure the accuracy of satellite positions and their clocks. In its present form, it has five monitoring stations, three ground antennas, and a master control station.

The *user* element consists of antennas and receiver/processors on board the aircraft that provide positioning, velocity, and precise timing to the user. GPS equipment used while operating under IFR must meet the standards set forth in Technical Standard Order (TSO) C-129 (or equivalent); meet the airworthiness installation requirements; be "approved" for that type of IFR operation; and be operated in accordance with the applicable POH/AFM or flight manual supplement.

An updatable GPS database that supports the appropriate operations (e.g., en route, terminal, and instrument approaches), is required when operating under IFR. The aircraft GPS navigation database contains waypoints from the geographic areas where GPS navigation has been approved for IFR operations. The pilot selects the desired waypoints from the database and may add **user-defined waypoints** for the flight.

Equipment approved in accordance with TSO C-115a, visual flight rules (VFR), 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. During IFR operations, these units (TSO C-115a) may only be considered as an aid to situational awareness.

Global positioning system (GPS): Navigation system using satellite rather than ground-based transmitters for location information.

User-defined waypoints: Waypoint location and other data which may be input by the user; this is the only database that may be altered (edited) by the user.

Function of GPS

GPS operation is based on the concept of ranging and triangulation from a group of satellites in space which act as precise reference points. The receiver uses data from a minimum of four satellites above the mask angle (the lowest angle above the horizon at which it can use a satellite).

The aircraft GPS receiver measures distance from a satellite using the travel time of a radio signal. Each satellite transmits a specific code, called a course/acquisition (CA) code, which contains information on the satellite's position, the GPS system time, and the health and accuracy of the transmitted data. Knowing the speed at which the signal traveled (approximately 186,000 miles per second) and the exact broadcast time, the distance traveled by the signal can be computed from the arrival time. The distance derived from this method of computing distance is called a pseudo-range because it is not a direct measurement of distance, but a measurement based on time. In addition to knowing the distance to a satellite, a receiver needs to know the satellite's exact position in space; this is know as its ephemeris. Each satellite transmits information about its exact orbital location. The GPS receiver uses this information to precisely establish the position of the satellite.

Using the calculated pseudo-range and position information supplied by the satellite, the GPS receiver/processor mathematically determines its position by triangulation from several satellites. The GPS receiver needs at least four satellites to yield a three-dimensional position (latitude, longitude, and altitude) and time solution. The GPS receiver computes navigational values (e.g., distance and bearing to a waypoint, groundspeed, etc.) by using the aircraft's known latitude/longitude and referencing these to a database built into the receiver.

The GPS receiver verifies the integrity (usability) of the signals received from the GPS constellation through **receiver autonomous integrity monitoring (RAIM)** to determine if a satellite is providing corrupted information. RAIM needs a minimum of five satellites in view, or four satellites and a barometric altimeter **baro-aiding** to detect an integrity anomaly. For receivers capable of doing so, RAIM needs six satellites in view (or five satellites with baro-aiding) to isolate a corrupt satellite signal and remove it from the navigation solution.

Generally there are two types of RAIM messages. One type indicates that there are not enough satellites available to provide RAIM and another type indicates that the RAIM has detected a potential error that exceeds the limit for the current phase of flight. Without RAIM capability, the pilot has no assurance of the accuracy of the GPS position.

Aircraft using GPS navigation equipment under IFR for domestic en route, terminal operations, and certain IAPs, must be equipped with an approved and operational alternate means of navigation appropriate to the flight. The avionics necessary to receive all of the ground-based facilities appropriate for the route to the destination airport and any required alternate airport must be installed and operational. Ground-based facilities necessary for these routes must also be operational. Active monitoring of alternative navigation equipment is not required if the GPS receiver uses RAIM for integrity monitoring. Active monitoring of an alternate means of navigation *is required* when the RAIM capability of the GPS equipment is lost. 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.

GPS Substitution

Aircraft 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 U.S. NAS.

1. Determining the aircraft position over a DME fix. This includes en route operations at and above 24,000 feet mean sea level (MSL) (FL240) when using GPS for navigation.
2. Flying a DME arc.
3. Navigating TO/FROM an NDB/compass locator.
4. Determining the aircraft position over an NDB/compass locator.
5. Determining the aircraft position over a fix defined by an NDB/compass locator bearing crossing a VOR/LOC course.
6. Holding over an NDB/compass locator.

Receiver autonomous integrity monitoring (RAIM): A system used to verify the usability of the received GPS signals, which warns the pilot of malfunctions in the navigation system.

Baro-aiding: Entering the current altimeter setting into the GPS receiver to aid RAIM.

Using GPS as a substitute for ADF or DME is subject to the following restrictions:

1. This equipment must be installed in accordance with appropriate airworthiness installation requirements and operated within the provisions of the applicable POH/AFM, or supplement.
2. The required integrity for these operations must be provided by at least en route RAIM, or equivalent.
3. Waypoints, fixes, intersections, and facility locations to be used for these operations must be retrieved from the GPS airborne database. The database must be current. If the required positions cannot be retrieved from the airborne database, the substitution of GPS for ADF and/or DME is not authorized.
4. Procedures must be established for use when RAIM outages are predicted or occur. This may require the flight to rely on other approved equipment or require the aircraft to be equipped with operational NDB and/or DME receivers. Otherwise, the flight must be rerouted, delayed, canceled, or conducted VFR.
5. The CDI must be set to terminal sensitivity (normally 1 or 1-1/4 NM) when tracking GPS course guidance in the terminal area.
6. A non-GPS approach procedure must exist at the alternate airport when one is required. If the non-GPS approaches on which the pilot must rely require DME or ADF, the aircraft must be equipped with DME or ADF avionics as appropriate.
7. Charted requirements for ADF and/or DME can be met using the GPS system, except for use as the principal instrument approach navigation source.

The following provides guidance which is not specific to any particular aircraft GPS system. For specific system guidance, refer to the POH/AFM, or supplement, or contact the system manufacturer.

To determine the aircraft position over a DME fix:

1. Verify aircraft GPS system integrity monitoring is functioning properly and indicates satisfactory integrity.
2. If the fix is identified by a five-letter name which is contained in the GPS airborne database, you may select either the named fix as the active GPS waypoint (WP) or the facility establishing the DME fix as the active GPS WP. When using a facility as the active WP, the only acceptable facility is the DME facility which is charted as the one used to establish the DME fix. If this facility is not in your airborne database, you are *not authorized* to use a facility WP for this operation.
3. If the fix is identified by a five-letter name which is not contained in the GPS airborne database, or if the fix is not named, you must select the facility establishing the DME fix or another named DME fix as the active GPS WP.
4. If you select the named fix as your active GPS WP, you are over the fix when the GPS system indicates you are at the active WP.
5. If you select the DME providing facility as the active GPS WP, you are over the fix when the GPS distance from the active WP equals the charted DME value, and you are on the appropriate bearing or course.

To fly a DME arc:

1. Verify aircraft GPS system integrity monitoring is functioning properly and indicates satisfactory integrity.
2. Select from the airborne database the facility providing the DME arc as the active GPS WP. The only acceptable facility is the DME facility on which the arc is based. If this facility is not in your airborne database, you are *not authorized* to perform this operation.
3. Maintain position on the arc by reference to the GPS distance instead of a DME readout.

To navigate TO or FROM an NDB/compass locator:

1. Verify aircraft GPS system integrity monitoring is functioning properly and indicates satisfactory integrity.
2. Select the NDB/compass locator facility from the airborne database as the active WP. If the chart depicts the compass locator collocated with a fix of the same name, use of that fix as the active WP in place of the compass locator facility *is authorized*.
3. Select and navigate on the appropriate course to or from the active WP.

To determine the aircraft position over an NDB/compass locator:

1. Verify aircraft GPS system integrity monitoring is functioning properly and indicates satisfactory integrity.
2. Select the NDB/compass locator facility from the airborne database. When using an NDB/compass locator, that facility must be charted and be in the airborne database. If this facility is not in your airborne database, you are *not authorized* to use a facility WP for this operation.
3. You are over the NDB/compass locator when the GPS system indicates you are at the active WP.

To determine the aircraft position over a fix made up of an NDB/compass locator bearing crossing a VOR/LOC course:

1. Verify aircraft GPS system integrity monitoring is functioning properly and indicates satisfactory integrity.
2. A fix made up by a crossing NDB/compass locator bearing will be identified by a five letter fix name. You may select either the named fix or the NDB/compass locator facility providing the crossing bearing to establish the fix as the active GPS WP. When using an NDB/compass locator, that facility must be charted and be in the airborne database. If this facility is not in your airborne database, you are *not authorized* to use a facility WP for this operation.
3. If you select the named fix as your active GPS WP, you are over the fix when the GPS system indicates you are at the WP as you fly the prescribed track from the non-GPS navigation source.
4. If you select the NDB/compass locator facility as the active GPS WP, and are over the fix when the GPS bearing to the active WP is the same as the charted NDB/compass locator bearing for the fix as you fly the prescribed track from the non-GPS navigation source.

To hold over an NDB/compass locator:

1. Verify aircraft GPS system integrity monitoring is functioning properly and indicates satisfactory integrity.
2. Select the NDB/compass locator facility from the airborne database as the active WP. When using a facility as the active WP, the only acceptable facility is the NDB/compass locator facility which is charted. If this facility is not in your airborne database, you are not authorized to use a facility WP for this operation.
3. Select nonsequencing (e.g. "HOLD" or "OBS") mode and the appropriate course in accordance with the POH/AFM, or supplement.
4. Hold using the GPS system in accordance with the POH/AFM, or supplement.

IFR Flight Using GPS

Preflight preparations should ensure that the GPS is properly installed and certified with a current database for the type of operation. The GPS operation must be conducted in accordance with the FAA-approved POH/AFM or flight manual supplement. Flightcrew members must be thoroughly familiar with the particular GPS equipment installed in the aircraft, the receiver operation manual, and the POH/AFM or flight manual supplement. Unlike ILS and VOR, the basic operation, receiver presentation to the pilot, and some capabilities of the equipment can vary greatly. Due to these differences, operation of different brands, or even models of the same brand of GPS receiver under IFR should not be attempted without thorough study of the operation of that particular receiver and installation. Using the equipment in flight under VFR conditions prior to attempting IFR operation will allow further familiarization.

Required preflight preparations should include checking NOTAMs relating to the IFR flight when using GPS as a supplemental method of navigation. GPS satellite outages are issued as GPS NOTAMs both domestically and internationally. Pilots may obtain GPS RAIM availability information for an airport by specifically requesting GPS aeronautical information from an automated flight service station (AFSS) during preflight briefings. GPS RAIM aeronautical information can be obtained for a 3 hour period: the estimated time of arrival (ETA), and 1 hour before to 1 hour after the ETA hour, or a 24 hour timeframe for a specific airport. FAA briefers will provide RAIM information for a period of 1 hour before to 1 hour after the ETA, unless a specific timeframe is requested by the pilot. If flying a published GPS departure, a RAIM prediction should also be requested for the departure airport. Some GPS receivers have the capability to predict RAIM availability. The pilot should also ensure that the required underlying ground-based navigation facilities and related aircraft equipment appropriate to the route of flight, terminal operations, instrument approaches for the destination, and alternate airports/heliports, will be operational for the ETA. If the *required* ground-based facilities and equipment will not be available, the flight should be rerouted, rescheduled, canceled, or conducted under VFR.

Except for programming and retrieving information from the GPS receiver, planning the flight is accomplished in a similar manner to conventional NAVAIDs. Departure waypoint, DP, route, STAR, desired approach, IAF, and destination airport are entered into the GPS receiver according to the manufacturer's instructions. During preflight, additional information may be entered for functions such as ETA, fuel planning, winds aloft, etc.

When the GPS receiver is turned on, it begins an internal process of test and initialization. When the receiver is initialized, the user develops the route by selecting a waypoint or series of waypoints, verifies the data, and selects the active flight plan. This procedure varies widely between the manufacturer's receivers. GPS is a complex system, offering little standardization between receiver models. It is the pilot's responsibility to be familiar with the operation of the equipment in the aircraft.

The GPS receiver provides navigational values such as track, bearing, groundspeed, and distance. These are computed from the aircraft's present latitude and longitude to the location of the next waypoint. Course guidance is provided between waypoints. The pilot has the advantage of knowing the aircraft's actual track over the ground. As long as track and bearing to the waypoint are matched up (by selecting the correct aircraft heading), the aircraft is going directly to the waypoint.

GPS Instrument Approaches

There is a mixture of GPS overlay approaches (approaches with "or GPS" in the title) and GPS stand-alone approaches in the U.S.

Note: GPS instrument approach operations outside the U.S. must be authorized by the appropriate country authority.

While conducting these IAPs, ground-based NAVAIDs are not required to be operational and associated aircraft avionics need not be installed, operational, turned on, or monitored; however, monitoring backup navigation systems is always recommended when available.

Pilots should have a basic understanding of GPS approach procedures and practice GPS IAPs under visual meteorological conditions (VMC) until thoroughly proficient with all aspects of their equipment (receiver and installation) prior to attempting flight in instrument meteorological conditions (IMC).

All IAPs must be retrievable from the current GPS database supplied by the manufacturer or other FAA-approved source. Flying point-to-point on the approach does not assure compliance with the published approach procedure. The proper RAIM sensitivity will not be available and the CDI sensitivity will not automatically change to 0.3 NM. Manually setting CDI sensitivity does not automatically change the RAIM sensitivity on some receivers. Some existing nonprecision approach procedures cannot be coded for use with GPS and will not be available as overlays.

GPS approaches are requested and approved by ATC using the GPS title such as "GPS RWY 24" or "RNAV RWY 35." Using the manufacturer's recommended procedures, the desired approach and the appropriate IAF are selected from the GPS receiver database. Pilots should fly the full approach from an initial approach waypoint (IAWP) or feeder fix unless specifically cleared otherwise. Randomly joining an approach at an intermediate fix does not ensure terrain clearance.

When an approach has been loaded in the flight plan, GPS receivers will give an "arm" annunciation 30 NM straight line distance from the airport/heliport reference point. The approach mode should be "armed" when within 30 NM distance so the receiver will change from en route CDI (±5 NM) and RAIM (±2 NM) sensitivity to ±1 NM terminal sensitivity. Where the IAWP is inside this 30 NM point, a CDI sensitivity change will occur once the approach mode is armed and the aircraft is inside 30 NM. Where the IAWP is beyond 30 NM point, CDI sensitivity will not change until the aircraft is within 30 NM point even if the approach is armed earlier. Feeder route obstacle clearance is predicated on the receiver CDI and RAIM being in terminal CDI sensitivity within 30 NM of the airport/heliport reference point; therefore, the receiver should always be armed not later than the 30 NM annunciation.

Pilots should pay particular attention to the exact operation of their GPS receivers for performing holding patterns and in the case of overlay approaches, operations such as procedure turns. These procedures may require manual intervention by the pilot to stop the sequencing of waypoints by the receiver and to resume automatic GPS navigation sequencing once the maneuver is complete. The same waypoint may appear in the route of flight more than once consecutively (e.g., IAWP, final approach waypoint (FAWP), missed approach waypoint (MAHWP) on a procedure turn). Care must be exercised to ensure the receiver is sequenced to the appropriate waypoint for the segment of the procedure being flown, especially if one or more fly-over waypoints are skipped (e.g., FAWP rather than IAWP if the procedure turn is not flown). The pilot may have to sequence past one or more fly-overs of the same waypoint in order to start GPS automatic sequencing at the proper place in the sequence of waypoints.

When receiving vectors to final, most receiver operating manuals suggest placing the receiver in the nonsequencing mode on the FAWP and manually setting the course. This provides an extended final approach course in cases where the aircraft is vectored onto the final approach course outside of any existing segment which is aligned with the runway. Assigned altitudes must be maintained until established on a published segment of the approach. Required altitudes at waypoints outside the FAWP or step-down fixes must be considered. Calculating the distance to the FAWP may be required in order to descend at the proper location.

When within 2 NM of the FAWP with the approach mode armed, the approach mode will switch to active, which results in RAIM and CDI sensitivity changing to the approach mode. Beginning 2 NM prior to the FAWP, the full scale CDI sensitivity will smoothly change from ±1 NM, to ±0.3 NM at the FAWP. As sensitivity changes from ±1 NM to ±0.3 NM approaching the FAWP, and the CDI not centered, the corresponding increase in CDI displacement may give the impression the aircraft is moving further away from the intended course even though it is on an acceptable intercept heading. Referencing the digital track displacement information (crosstrack error), if it is available in the approach mode, may help the pilot remain position oriented in this situation. Being established on the final approach course prior to the beginning of the sensitivity change at 2 NM, will help prevent problems in interpreting the CDI display during **ramp-down**. Requesting or accepting vectors, which will cause the aircraft to intercept the final approach course within 2 NM of the FAWP, is not recommended.

Incorrect inputs into the GPS receiver are especially critical during approaches. In some cases, an incorrect entry can cause the receiver to leave the approach mode. Overriding an automatically selected sensitivity during an approach will cancel the approach mode annunciation. If the approach mode is not armed by 2 NM prior to the FAWP, the approach mode will not become active at 2 NM prior to the FAWP, and the equipment will flag. In these conditions, the RAIM and CDI sensitivity will not ramp down, and the pilot should not descend to minimum descent altitude (MDA), but fly to the MAWP and execute a missed approach. The approach active annunciator and/or the receiver should be checked to ensure the approach mode is active prior to the FAWP.

A GPS missed approach requires pilot action to sequence the receiver past the MAWP to the missed approach portion of the procedure. The pilot must be thoroughly familiar with the activation procedure for the particular GPS receiver installed in the aircraft and must initiate appropriate action after the MAWP. Activating the missed approach prior to the MAWP will cause CDI sensitivity to immediately change to terminal (±1 NM) sensitivity and the receiver will continue to navigate to the MAWP. The receiver will not sequence past the MAWP. Turns should not begin prior to the MAWP. If the missed approach is not activated, the GPS receiver will display an extension of the inbound final approach course and the along track distance (ATD) will increase from the MAWP until it is manually sequenced after crossing the MAWP.

Missed approach routings in which the first track is via a course rather than direct to the next waypoint require additional action by the pilot to set the course. Being familiar with all of the inputs required is especially critical during this phase of flight.

If proceeding to an alternate airport, the avionics necessary to receive all of the ground-based facilities appropriate for the route to the alternate airport must be installed and operational. The alternate airport must be served by an approach based on other than GPS or LORAN-C navigation, the aircraft must have operational equipment capable of using that navigation aid, and the required navigation aid must be operational.

GPS Errors

Normally, with 24 satellites in operation, the GPS constellation is expected to be available continuously worldwide. Whenever there is less than 24 operational satellites, at times GPS navigational capability may not be available at certain geographic locations. Loss of signals may also occur in valleys surrounded by high terrain, and any time the aircraft's GPS antenna is "shadowed" by the aircraft's structure (e.g., when the aircraft is banked).

Certain receivers, transceivers, mobile radios, and portable receivers can cause signal interference. Some VHF transmissions may cause "harmonic interference." Pilots can isolate the interference by relocating nearby portable receivers, changing frequencies, or turning off suspected causes of the interference while monitoring the receiver's signal quality data page.

GPS position data can be affected by equipment characteristics and various geometric factors, which typically cause errors of less than 100 feet. Satellite atomic clock inaccuracies, receiver/processors, signals reflected from hard objects (multipath), ionospheric and tropospheric delays, and satellite data transmission errors may cause small position errors or momentary loss of the GPS signal.

Selective availability (SA) is a method by which the DOD can, in the interest of national security, create a significant clock and ephemeris error in the satellites. When SA is active, daily predictable horizontal accuracy for any position is

Ramp-down: Changing CDI and RAIM from en route to terminal sensitivity, or terminal to approach sensitivity.

Selective availability (SA): A method by which the DOD can, in the interest of national security, create a significant clock and ephemeris error in the satellites, resulting in a navigation error.

within 300 meters or better, 99.99 percent of the time, and within 100 meters or better 95 percent of the time. Daily, predictable vertical accuracy for any position will be within 500 meters or better 99.99 percent of the time, or within 156 meters or better 95 percent of the time. Time is accurate within 900 nanoseconds of universal coordinated time (UTC) 99.99 percent of the time, and within 300 nanoseconds 95 percent of the time. With all of the errors compounded, position data is more accurate than other present day navigational systems.

GPS derived altitude should not be relied upon to determine aircraft altitude since the vertical error can be quite large.

Inertial Navigation System (INS)

INS is a system that navigates precisely by dead reckoning, without any input from outside of the aircraft. It is fully self-contained. The INS is initialized by the pilot, who enters into the system its exact location while the aircraft is on the ground before the flight. The INS is also programmed with waypoints along the desired route of flight.

INS Components

INS is considered a stand-alone navigation system, especially when more than one independent unit is onboard. The airborne equipment consists of an accelerometer to measure acceleration—which, when integrated with time, gives velocity—and gyros to measure direction.

Later versions of the INS, called IRS (inertial reference systems) utilize laser gyros and more powerful computers; therefore, the accelerometer mountings no longer need to be kept level and aligned with true north. The computer system can handle the added workload of dealing with the computations necessary to correct for gravitational and directional errors. Consequently, these newer systems are sometimes called strapdown systems, as the accelerometers and gyros are strapped down to the airframe, rather than being mounted on a structure that stays fixed with respect to the horizon and true north.

INS Errors

The principal error associated with INS is degradation of position with time. INS computes position by starting with an accurate position input which is changed continuously as accelerometers and gyros provide speed and direction inputs. Both the accelerometers and the gyros are subject to very small errors; as time passes, those errors likely will accumulate.

While the best INS/IRS display errors of 0.1 to 0.4 NM after flights across the North Atlantic of 4 to 6 hours, smaller and less expensive systems are being built that show errors of 1 to 2 NM per hour. This accuracy is more than sufficient for a navigation system that can be combined with and updated by GPS. The synergy of a navigation system consisting of an INS/IRS unit in combination with a GPS resolves the errors and weaknesses of both systems. The GPS is accurate all the time it is working but may be subject to short and periodic outages. The INS is made more accurate because it is continually updated and will continue to function with good accuracy if the GPS has moments of lost signal.

Instrument Approach Systems

Description

Most navigation systems approved for en route and terminal operations under IFR, such as VOR, NDB, and GPS, may also be approved to conduct IAPs. The most common systems in use in the U.S. are the ILS, simplified landing facility (SDF), localizer directional aid (LDA), and microwave landing system (MLS). These systems operate independently of other navigation systems. There are new systems being developed, such as wide area augmentation system (WAAS), local area augmentation system (LAAS), and other systems have been developed for special use.

Instrument Landing Systems (ILS)

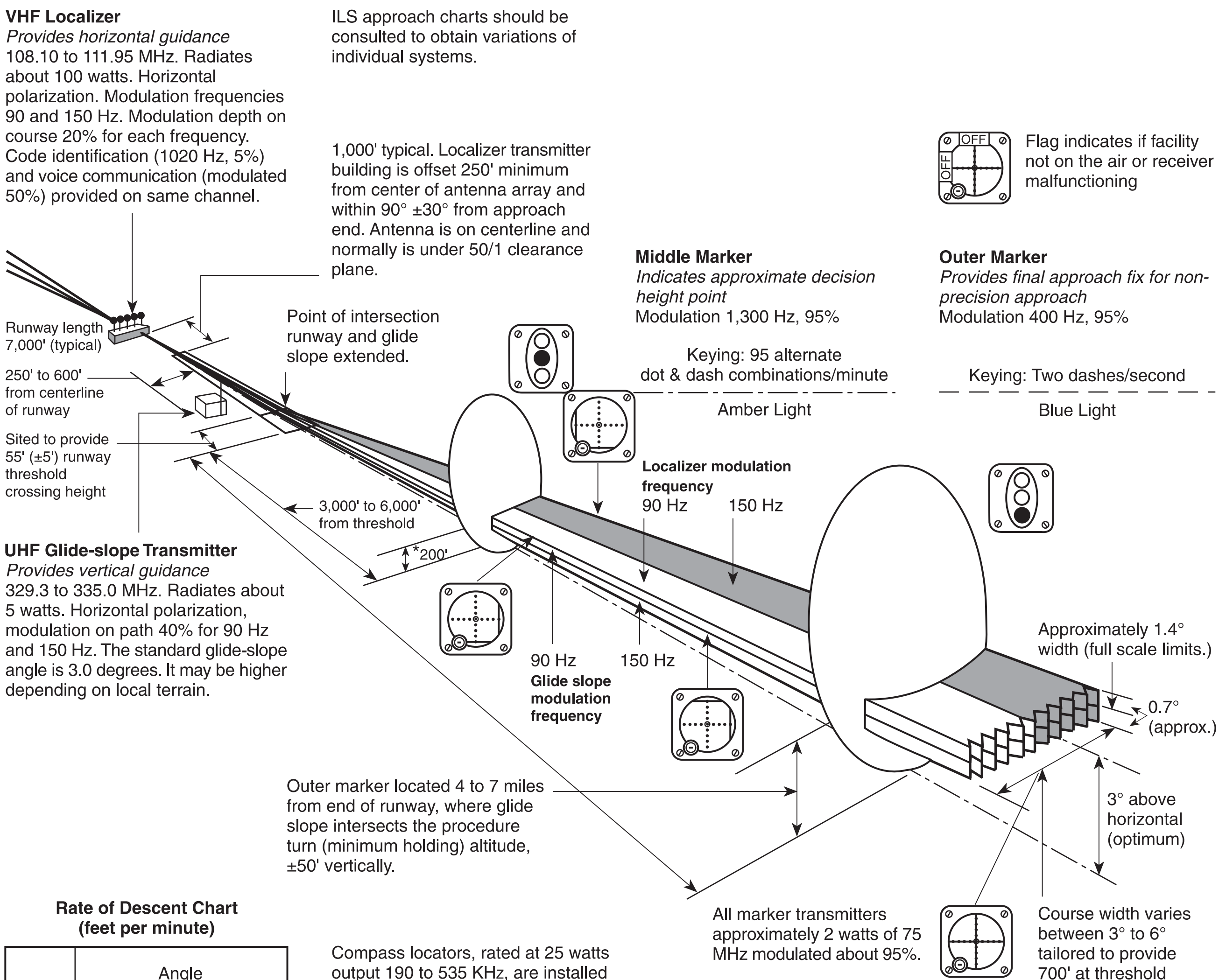
The **ILS** system provides both course and altitude guidance to a specific runway. The ILS system is used to execute a precision instrument approach procedure or **precision approach**. [Figure 7-23] The system consists of the following components:

1. A localizer provides horizontal (left/right) guidance along the extended centerline of the runway.
2. A glide slope provides vertical (up/down) guidance toward the runway touchdown point, usually at a 3° slope.
3. Marker beacons provide range information along the approach path.
4. Approach lights assist in the transition from instrument to visual flight.

Inertial navigation system (INS): A computer-based navigation system that tracks the movement of an aircraft by signals produced by onboard accelerometers.

Instrument landing system (ILS): An electronic system that provides both horizontal and vertical guidance to a specific runway, used to execute a precision instrument approach procedure.

Precision approach: An instrument approach procedure in which both course and glide-slope information is provided.



Rate of Descent Chart (feet per minute)

Speed (Knots)	Angle		
	2.5°	2.75°	3°
90	400	440	475
110	485	535	585
130	575	630	690
150	665	730	795
160	707	778	849

Compass locators, rated at 25 watts output 190 to 535 KHz, are installed at many outer and some middle markers. A 400 Hz or a 1020 Hz tone, modulating the carrier about 95%, is keyed with the first two letters of the ILS identification on the outer locator and the last two letters on the middle locator. At some locations, simultaneous voice transmissions from the control tower are provided, with appropriate reduction in identification percentage.

*Figures marked with asterisk are typical. Actual figures vary with deviations in distances to markers, glide angles and localizer widths.

Figure 7-23. *Instrument landing systems.*

The following supplementary elements, though not specific components of the system, may be incorporated to increase safety and utility:

1. Compass locators provide transition from en route NAVAIDs to the ILS system; they assist in holding procedures, tracking the localizer course, identifying the marker beacon sites, and providing a FAF for ADF approaches.
2. DME colocated with the glide-slope transmitter provide positive distance-to-touchdown information or DME associated with another nearby facility (VOR or stand-alone), if specified in the approach procedure.

ILS approaches are categorized into three different types of approaches, based on the equipment at the airport and the experience level of the pilot. Category I approaches provide for approach height above touchdown of not less than 200 feet. Category II approaches provide for approach to a height above touchdown of not less than 100 feet. Category III approaches provide lower minimums for approaches without a decision height minimum. While pilots must only be instrument rated and the aircraft be equipped with the appropriate airborne equipment to execute Category I approaches, Category II and III approaches require special certification for the pilots, ground equipment, and airborne equipment.

ILS Components

Ground Components

The ILS uses a number of different ground facilities. These facilities may be used as a part of the ILS system, as well as part of another approach. For example, the compass locator may be used with NDB approaches.

Localizer

The **localizer (LOC)** ground antenna array is located on the extended centerline of the instrument runway of an airport, remote enough from the opposite (approach) end of the runway to prevent it from being a collision hazard. This unit radiates a field pattern, which develops a course down the centerline of the runway toward the **middle markers (MMs)** and **outer markers (OMs)**, and a similar course along the runway centerline in the opposite direction. These are called the *front* and *back courses*, respectively. The localizer provides course guidance, transmitted at 108.1 to 111.95 MHz (odd tenths only), throughout the descent path to the runway threshold from a distance of 18 NM from the antenna to an altitude of 4,500 feet above the elevation of the antenna site. [Figure 7-24]

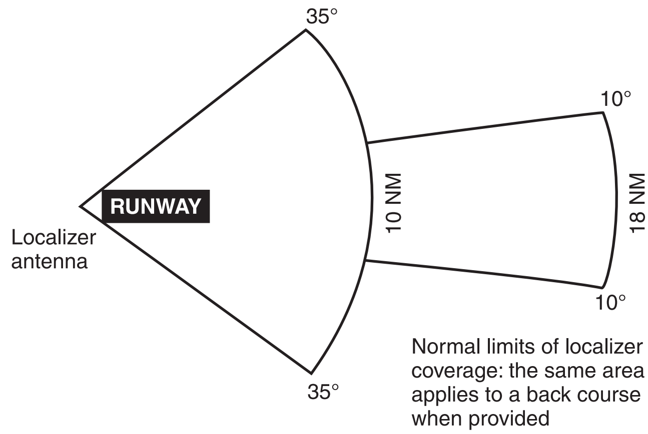


Figure 7-24. *Localizer coverage limits.*

The localizer course width is defined as the angular displacement at any point along the course between a full "fly-left" (CDI needle fully deflected to the left) and a full "fly-right" indication (CDI needle fully deflected to the right.) Each localizer facility is audibly identified by a three-letter designator, transmitted at frequent regular intervals. The ILS identification is preceded by the letter "I" (two dots). For example, the ILS localizer at Springfield, Missouri transmits the identifier ISGF. The localizer includes a voice feature on its frequency for use by the associated ATC facility in issuing approach and landing instructions.

The localizer course is very narrow, normally 5°. This results in high needle sensitivity. With this course width, a full-scale deflection shows when the aircraft is 2.5° to either side of the centerline. This sensitivity permits accurate orientation to the landing runway. With no more than one-quarter scale deflection maintained, the aircraft will be aligned with the runway. [Figure 7-25]

Localizer (LOC): The portion of the ILS that gives left/right guidance information down the centerline of the instrument runway for final approach.

Middle marker (MM): VHF marker beacon used in the ILS. When the NDB compass locator is colocated with an MM, it is shown as LMM on instrument approach charts.

Outer marker (OM): VHF marker beacon used in the ILS. When the NDB compass locator is colocated with an OM, it is shown as LOM on instrument approach charts.

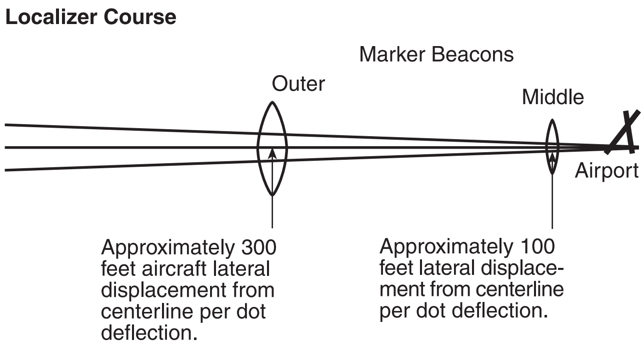


Figure 7-25. *Localizer receiver indications and aircraft displacement.*

Glide Slope

Glide slope (GS) describes the systems that generate, receive, and indicate the ground facility radiation pattern. The glidepath is the straight, sloped line the aircraft should fly in its descent from where the glide slope intersects the altitude used for approaching the FAF, to the runway touchdown zone. The glide-slope equipment is housed in a building approximately 750 to 1,250 feet down the runway from the approach end of the runway, and between 400 and 600 feet to one side of the centerline.

The course projected by the glide-slope equipment is essentially the same as would be generated by a localizer operating on its side. The glide-slope projection angle is normally adjusted to 2.5° to 3.5° above horizontal, so it intersects the MM at about 200 feet and the OM at about 1,400 feet above the runway elevation. At locations where standard minimum obstruction clearance cannot be obtained with the normal maximum glide-slope angle, the glide-slope equipment is displaced farther from the approach end of the runway if the length of the runway permits; or, the glide-slope angle may be increased up to 4°.

Unlike the localizer, the glide-slope transmitter radiates signals only in the direction of the final approach on the front course. The system provides no vertical guidance for approaches on the back course. The glidepath is normally 1.4° thick. At 10 NM from the point of touchdown, this represents a vertical distance of approximately 1,500 feet, narrowing to a few feet at touchdown.

Marker Beacons

Two VHF marker beacons, outer and middle, are normally used in the ILS system. A third beacon, the inner, is used where Category II operations are certified. A **marker beacon** may also be installed to indicate the FAF on the ILS back course.

The OM is located on the localizer front course 4 to 7 miles from the airport to indicate a position at which an aircraft, at the appropriate altitude on the localizer course, will intercept the glidepath. The MM is located approximately 3,500 feet from the landing threshold on the centerline of the localizer front course at a position where the glide-slope centerline is about 200 feet above the touchdown zone elevation. The inner marker (IM), where installed, is located on the front course between the MM and the landing threshold. It indicates the point at which an aircraft is at the decision height on the glidepath during a Category II ILS approach. The back-course marker, where installed, indicates the back-course FAF.

Compass Locator

Compass locators are low-powered NDBs and are received and indicated by the ADF receiver. When used in conjunction with an ILS front course, the compass locator facilities are colocated with the outer and/or MM facilities. The coding identification of the outer locator consists of the *first* two letters of the three-letter identifier of the associated LOC. For example, the outer locator at Dallas/Love Field (DAL) is identified as "DA." The middle locator at DAL is identified by the last two letters "AL."

Approach Lighting Systems (ALS)

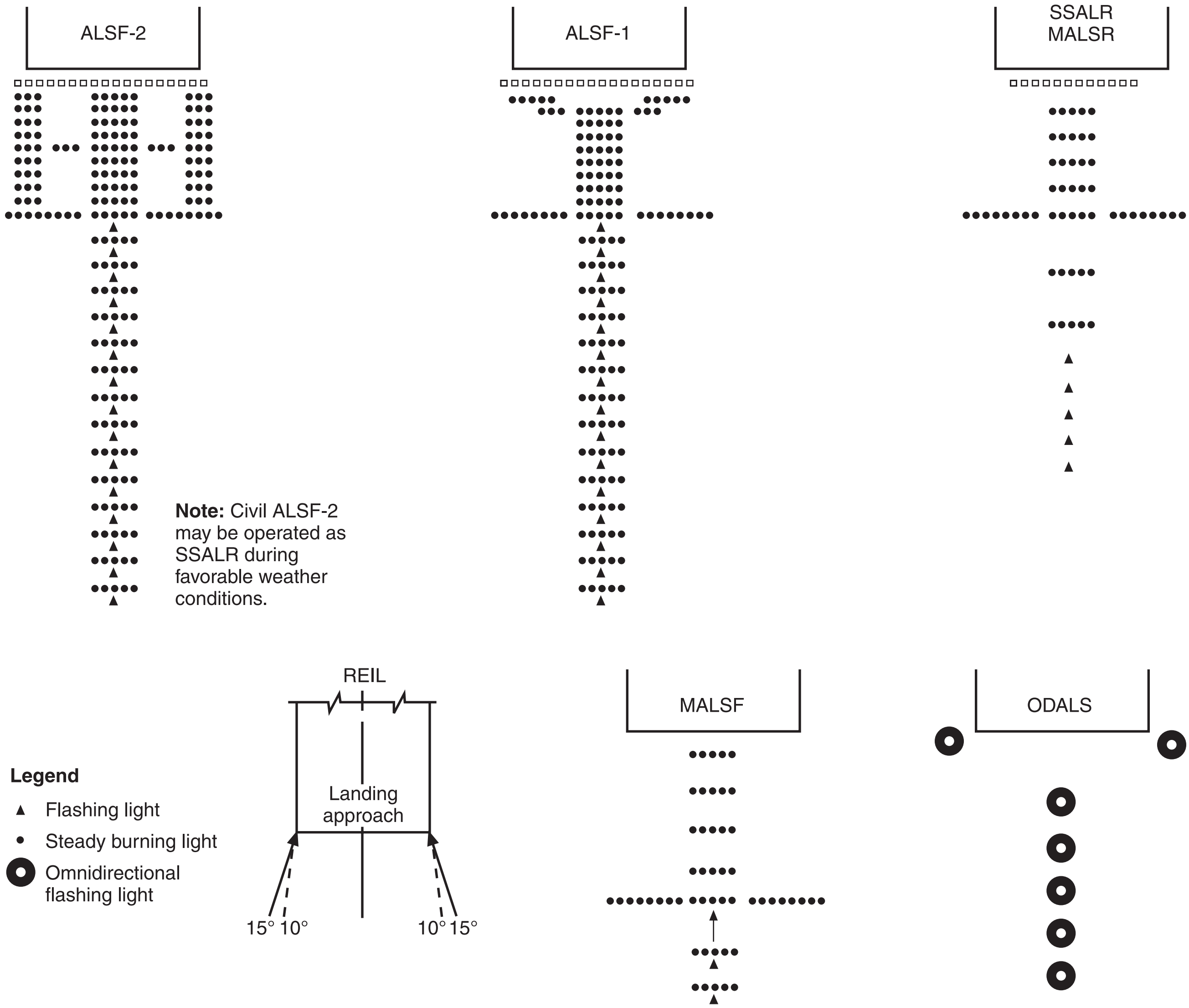
Normal approach and letdown on the ILS is divided into two distinct stages: the instrument approach stage using only radio guidance, and the visual stage, when visual contact with the ground runway environment is necessary for accuracy and safety. The most critical period of an instrument approach, particularly during low ceiling/visibility conditions, is the point at which the pilot must decide whether to land or execute a missed approach. As the runway threshold is approached, the visual glidepath will separate into individual lights. At this point, the approach should be continued by reference to the runway touchdown zone markers. The ALS provides lights that will penetrate the atmosphere far enough from touchdown to give directional, distance, and glidepath information for safe visual transition.

Glide slope (GS): 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.

Marker beacon: 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.

Visual identification of the ALS by the pilot must be instantaneous, so it is important to know the type of ALS before the approach is started. Check the instrument approach chart and the A/FD for the particular type of lighting facilities at the destination airport before any instrument flight. With reduced visibility, rapid orientation to a strange runway can be difficult, especially during a circling approach to an airport with minimum lighting facilities, or to a large terminal airport located in the midst of distracting city and ground facility lights. Some of the most common ALS systems are shown in figure 7-26.

A high-intensity flasher system, often referred to as "the rabbit," is installed at many large airports. The flashers consist of a series of brilliant blue-white bursts of light flashing in sequence along the approach lights, giving the effect of a ball of light traveling towards the runway. Typically, "the rabbit" makes two trips toward the runway per second.



ALSF—Approach light system with sequenced flashing lights

SSALR—Simplified short approach light system with runway alignment indicator lights

MALSR—Medium intensity approach light system with runway alignment indicator lights

REIL—Runway end identification lights

MALSF—Medium intensity approach light system with sequenced flashing lights (and runway alignment)

ODALS—Omnidirectional approach light system

Figure 7-26. *Precision and nonprecision ALS configuration.*

Runway end identifier lights (REIL) are installed for rapid and positive identification of the approach end of an instrument runway. The system consists of a pair of synchronized flashing lights placed laterally on each side of the runway threshold facing the approach area.

The visual approach slope indicator (VASI) gives visual descent guidance information during the approach to a runway. The standard VASI consists of light bars that project a visual glidepath, which provides safe obstruction clearance within the approach zone. The normal glide-slope angle is 3°; however, the angle may be as high as 4.5° for proper obstacle clearance. On runways served by ILS, the VASI angle normally coincides with the electronic glide-slope angle. Visual left/right course guidance is obtained by alignment with the runway lights. The standard VASI installation consists of either 2-, 3-, 4-, 6-, 12-, or 16-light units arranged in downwind and upwind light bars. Some airports serving long-bodied aircraft have three-bar VASIs which provide two visual glidepaths to the same runway. The first glidepath encountered is the same as provided by the standard VASI. The second glidepath is about 25 percent higher than the first and is designed for the use of pilots of long-bodied aircraft.

The basic principle of VASI is that of color differentiation between red and white. Each light projects a beam having a white segment in the upper part and a red segment in the lower part of the beam. From a position above the glidepath the pilot sees both bars as white. Lowering the aircraft with respect to the glidepath, the color of the upwind bars changes from white to pink to red. When on the proper glidepath, the landing aircraft will overshoot the downwind bars and undershoot the upwind bars. Thus the downwind (closer) bars are seen as white and the upwind bars as red. From a position below the glidepath both light bars are seen as red. Moving up to the glidepath, the color of the downwind bars changes from red to pink to white. When below the glidepath, as indicated by a distinct all-red signal, a safe obstruction clearance might not exist. A standard two-bar VASI is illustrated in figure 7-27.

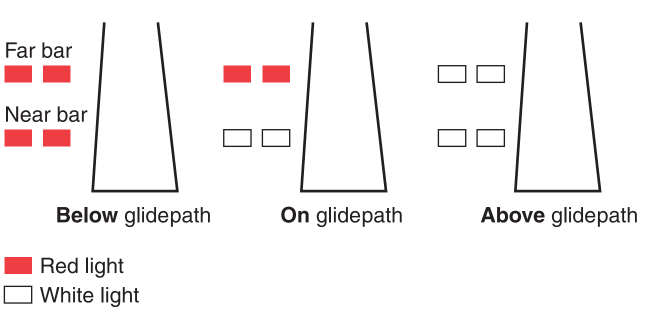


Figure 7-27. *Standard 2-bar VASI.*

ILS Airborne Components

Airborne equipment for the ILS system includes receivers for the localizer, glide slope, marker beacons, ADF, DME, and the respective indicator instruments.

The typical VOR receiver is also a localizer receiver with common tuning and indicating equipment. Some receivers have separate function selector switches, but most switch between VOR and LOC automatically by sensing if odd tenths between 108 and 111.95 MHz have been selected. Otherwise, tuning of VOR and localizer frequencies is accomplished with the same knobs and switches, and the CDI indicates "on course" as it does on a VOR radial.

Though some glide-slope receivers are tuned separately, in a typical installation the glide slope is tuned automatically to the proper frequency when the localizer is tuned. Each of the 40 localizer channels in the 108.10 to 111.95 MHz band is paired with a corresponding glide-slope frequency.

When the localizer indicator also includes a glide-slope needle, the instrument is often called a cross-pointer indicator. The crossed horizontal (glide slope) and vertical (localizer) needles are free to move through standard five-dot deflections to indicate position on the localizer course and glidepath.

When the aircraft is on the glidepath, the needle is horizontal, overlying the reference dots. Since the glidepath is much narrower than the localizer course (approximately 1.4° from full up to full down deflection), the needle is very sensitive to displacement of the aircraft from on-path alignment. With the proper rate of descent established upon glide-slope interception, very small corrections keep the aircraft aligned.

The localizer and glide-slope warning flags disappear from view on the indicator when sufficient voltage is received to actuate the needles. The flags show when an unstable signal or receiver malfunction occurs.

The OM is identified by a low-pitched tone, continuous dashes at the rate of two per second, and a purple/blue marker beacon light. The MM is identified by an intermediate tone, alternate dots and dashes at the rate of 95 dot/dash combinations per minute, and an amber marker beacon light. The IM, where installed, is identified by a high-pitched tone, continuous dots at the rate of six per second, and a white marker beacon light. The back-course marker (BCM), where installed, is identified by a high-pitched tone with two dots at a rate of 72 to 75 two-dot combinations per minute, and a white marker beacon light. Marker beacon receiver sensitivity is selectable as high or low on many units. The low-sensitivity position gives the sharpest indication of position and should be used during an approach. The high-sensitivity position provides an earlier warning that the aircraft is approaching the marker beacon site.

ILS Function

The localizer needle indicates, by deflection, whether the aircraft is right or left of the localizer centerline, regardless of the position or heading of the aircraft. Rotating the OBS has no effect on the operation of the localizer needle, although it is useful to rotate the OBS to put the LOC inbound course under the course index. When inbound on the front course, or outbound on the back course, the course indication remains **directional**. (*See* figure 7-28, aircraft C, D, and E.)

Unless the aircraft has reverse sensing capability and it is in use, when flying inbound on the back course or outbound on the front course, heading corrections to on-course are made opposite the needle deflection. This is commonly described as "flying away from the needle." (*See* figure 7-28, aircraft A and B.) Back course signals should not be used for an approach unless a back course approach procedure is published for that particular runway and the approach is authorized by ATC.

Once you have reached the localizer centerline, maintain the inbound heading until the CDI moves off center. Drift corrections should be small and reduced proportionately as the course narrows. By the time you reach the OM, your drift correction should be established accurately enough on a well-executed approach to permit completion of the approach, with heading corrections no greater then 2°.

The heaviest demand on pilot technique occurs during descent from the OM to the MM, when you maintain the localizer course, adjust pitch attitude to maintain the proper rate of descent, and adjust power to maintain proper airspeed. Simultaneously, the altimeter must be checked and preparation made for visual transition to land or for a missed approach. You can appreciate the need for accurate instrument interpretation and aircraft control within the ILS as a whole, when you notice the relationship between CDI and glidepath needle indications, and aircraft displacement from the localizer and glidepath centerlines.

Directional: Heading corrections toward on-course are made in the same direction as needle deflection.

ILS inbound course is 180°:

- **A.** As you pass over the FAF with a left turn to north, radio tuned to ILS and identified, course needle is "reverse sensing"; correct to left to center the course needle.
- **B.** As you begin procedure turn, course needle shows divergence from course centerline increasing.
- **C.** Procedure turn inbound, course needle no longer is reverse sensing. Start turn to final approach course when needle "comes alive" (needle moves away from side).
- **D.** Maintain course with the needle centered.
- **E.** As you fly a missed approach out the back course, the needle indicates "fly left" to get back on course centerline.

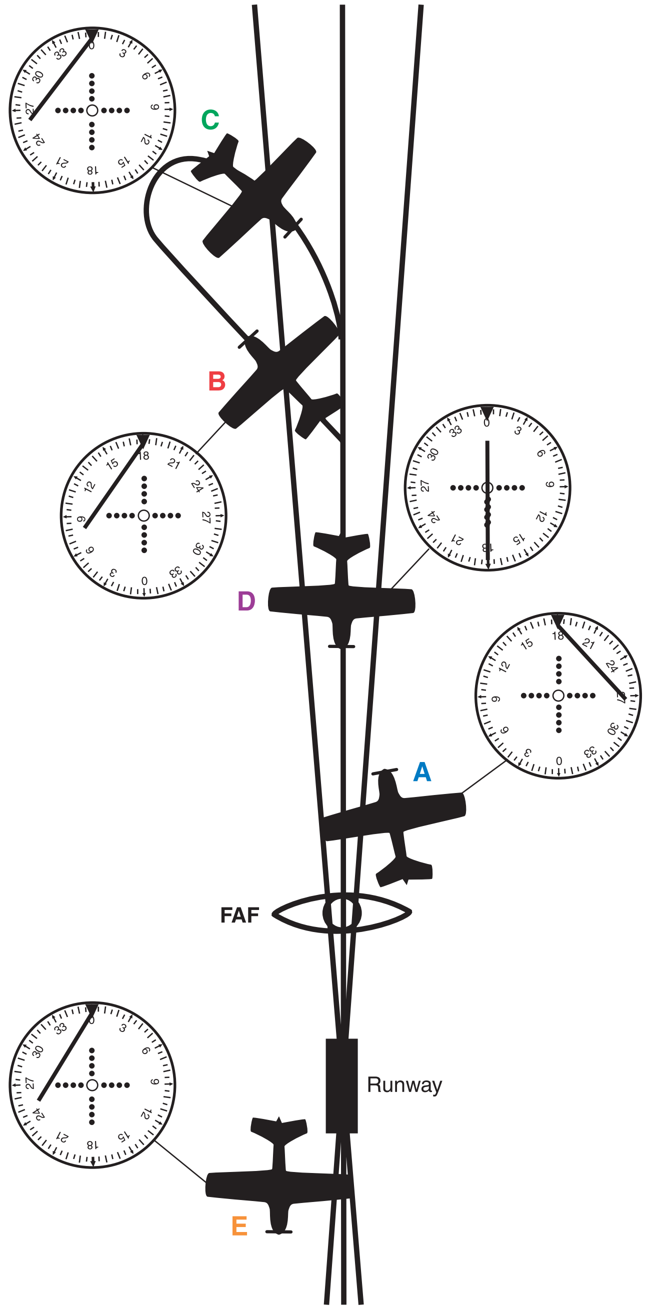


Figure 7-28. *Localizer course indications.*

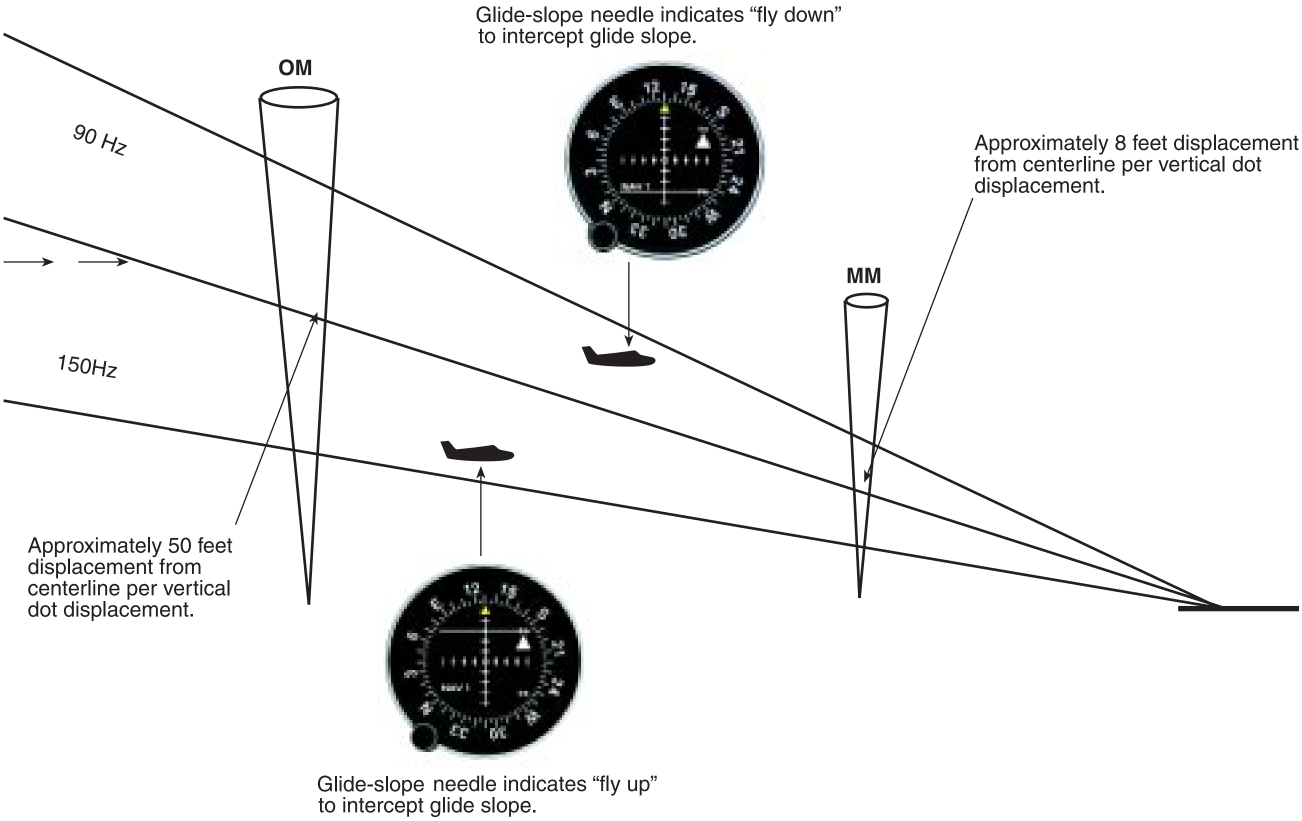


Figure 7-29. *Glide-slope receiver indications and aircraft displacement.*

Deflection of the glide-slope needle indicates the position of the aircraft with respect to the glidepath. When the aircraft is above the glidepath, the needle is deflected downward. When the aircraft is below the glidepath, the needle is deflected upward. [Figure 7-29]

ILS Errors

The ILS and its components are subject to certain errors, which are listed below.

Localizer and glide-slope signals are subject to the same type of bounce from hard objects as space waves.

1. Reflection. Surface vehicles and even other aircraft flying below 5,000 feet above ground level (AGL) may disturb the signal for aircraft on the approach.
2. False courses. In addition to the desired course, glide-slope facilities inherently produce additional courses at higher vertical angles. The angle of the lowest of these false courses will occur at approximately 9°–12°. An aircraft flying the LOC/glide-slope course at a constant altitude would observe gyrations of both the glide-slope needle and glide-slope warning flag as the aircraft passed through the various false courses. Getting established on one of these false courses will result in either confusion (reversed glide-slope needle indications), or result in the need for a very high descent rate. However, if the approach is conducted at the altitudes specified on the appropriate approach chart, these false courses will not be encountered.

Marker Beacons

The very low power and directional antenna of the marker beacon transmitter ensures that the signal will not be received any distance from the transmitter site. Problems with signal reception are usually caused by the airborne receiver not being turned on, or by incorrect receiver sensitivity.

Some marker beacon receivers, to decrease weight and cost, are designed without their own power supply. These units utilize a power source from another radio in the avionics stack, often the ADF. In some aircraft, this requires the ADF to be turned on in order for the marker beacon receiver to function, yet no warning placard is required. Another source of trouble may be the "High/Low/Off" three-position switch, which both activates the receiver and selects receiver sensitivity. Usually, the "test" feature only tests to see if the light bulbs in the marker beacon lights are working. Therefore, in some installations, there is no functional way for the pilot to ascertain the marker beacon receiver is actually on except to fly over a marker beacon transmitter, and see if a signal is received and indicated (e.g., audibly and marker beacon lights).

Operational Errors

1. Failure to understand the fundamentals of ILS ground equipment, particularly the differences in course dimensions. Since the VOR receiver is used on the localizer course, the assumption is sometimes made that interception and tracking techniques are identical when tracking localizer courses and VOR radials. Remember that the CDI sensing is sharper and faster on the localizer course.
2. Disorientation during transition to the ILS due to poor planning and reliance on one receiver instead of on all available airborne equipment. Use all the assistance you have available; the single receiver you may be relying on may fail at a busy time.
3. Disorientation on the localizer course, due to the first error noted above.
4. Incorrect localizer interception angles. A large interception angle usually results in overshooting, and possible disorientation. When intercepting, if possible, turn to the localizer course heading immediately upon the first indication of needle movement. An ADF receiver is an excellent aid to orient you during an ILS approach if there is a locator or NDB on the inbound course.
5. Chasing the CDI and glidepath needles, especially when you have not sufficiently studied the approach *before* the flight.

Simplified Directional Facility (SDF)

The SDF provides a final approach course similar to the ILS localizer. The SDF course may or may not be aligned with the runway and the course may be wider than a standard ILS localizer, resulting in less precision. Usable off-course indications are limited to 35° either side of the course centerline. Instrument indications in the area between 35° and 90° from the course centerline are not controlled and should be disregarded.

The SDF antenna may be offset from the runway centerline. Because of this, the angle of convergence between the final approach course and the runway bearing should be determined by reference to the instrument approach chart. This angle is usually not more than 3°. You should note this angle since the approach course originates at the antenna site, and an approach continued beyond the runway threshold would lead the aircraft to the SDF offset position rather than along the runway centerline.

The course width of the SDF signal emitted from the transmitter is fixed at either 6° or 12°, as necessary, to provide maximum flyability and optimum approach course quality. A three-letter identifier is transmitted in code on the SDF frequency; there is no letter "I" (two dots) transmitted before the station identifier, as there is with the LOC. For example, the identifier for Lebanon, Missouri, SDF is LBO.

Localizer Type Directional Aid (LDA)

The LDA is of comparable utility and accuracy to a localizer but is not part of a complete ILS. The LDA course width is between 3° and 6° and thus provides a more precise approach course than an SDF installation. Some LDAs are equipped with a glide slope. The LDA course is not aligned with the runway, but straight-in minimums may be published where the angle between the runway centerline and the LDA course does not exceed 30°. If this angle exceeds 30°, only circling minimums are published. The identifier is three letters preceded by "I" transmitted in code on the LDA frequency. For example, the identifier for Van Nuys, California, LDA is I-BUR.

Microwave Landing System (MLS)

The Microwave Landing System (MLS) provides precision approach navigation guidance. Transmitting in the frequency range of 5031 to 5091 MHz, it provides azimuth (left/right) and elevation (glide slope) information, displayed either on conventional CDIs or with multifunction cockpit displays. Range information is also provided.

MLS requires separate airborne equipment to receive and process the signals from what is normally installed in general aviation aircraft today. It has data communications capability, and can provide audible information about the condition of the transmitting system and other pertinent data such as weather, runway status, etc. The MLS transmits an audible identifier consisting of four letters beginning with the letter M, in Morse code at a rate of at least six per minute. The MLS system monitors itself and transmits ground-to-air data messages about the system's operational condition. During periods of routine or emergency maintenance, the coded identification is missing from the transmissions.

The MLS is made up of an approach azimuth station (transmitter/antenna) with data transmission capability, an elevation station, a range station, and sometimes a back azimuth station.

Approach Azimuth Station

The approach azimuth station, unlike ILS, is able to provide approach guidance along any path within its ±40° (to runway alignment) range. [Figure 7-30] Therefore, curved and segmented approaches are possible. This facility also provides the data communications capability of the system. This station is normally located about 1,000 feet beyond the stop end of the runway, but beyond this limitation there is considerable latitude in actual station location. A back azimuth station may be operating in conjunction with the approach azimuth station. If so, lateral guidance is available for missed approach and departure navigation.

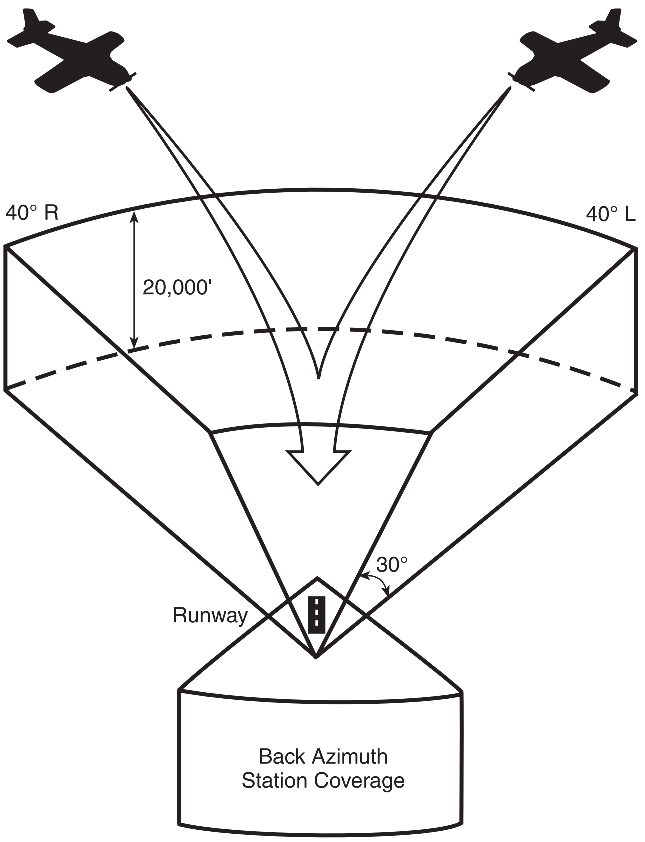


Figure 7-30. *MLS coverage volumes, 3-D representation.*

Elevation Guidance Station

Like the approach azimuth station, the elevation guidance station has considerably more capability than the ILS glide-slope system. Approach glidepath angles are selectable over a wide range up to at least 15°, with coverage to a maximum of 30°. This provides considerable flexibility for developing multipath approaches.

Range Guidance Station

The range guidance station transmits both normal and precision DME (DME/P) signals that function the same as normal DME (DME/N), with some technical and accuracy differences. Accuracy is improved to be consistent with the accuracy provided by the MLS azimuth and elevation stations.

Flight Management Systems (FMS)

Description

The Flight Management Systems (FMS) is not a navigation system in itself. Rather, it is a system that automates the tasks of managing the onboard navigation systems. FMS may perform other onboard management tasks, but this discussion is limited to its navigation function.

FMS is an interface between flightcrews and flight-deck systems. FMS can be thought of as a computer with a large database of airport and NAVAID locations and associated data, aircraft performance data, airways, intersections, DPs, and STARs. FMS also has the ability to accept and store numerous user-defined waypoints, flight routes consisting of departures, waypoints, arrivals, approaches, alternates, etc. FMS can quickly define a desired route from the aircraft's current position to any point in the world, perform flight plan computations, and display the total picture of the flight route to the crew.

FMS also has the capability of controlling (selecting) VOR, DME, and LOC NAVAIDs, and then receiving navigational data from them. INS, LORAN, and GPS navigational data may also be accepted by the FMS computer. The FMS may act as the input/output device for the onboard navigation systems, so that it becomes the "go-between" for the crew and the navigation systems.

Function of FMS

At startup, the crew programs the aircraft location, departure runway, DP (if applicable), waypoints defining the route, approach procedure, approach to be used, and routing to alternate. This may be entered manually, be in the form of a stored flight plan, or be a flight plan developed in another computer and transferred by disk or electronically to the FMS computer. The crew enters this basic information in the control/display unit (CDU). [Figure 7-31]

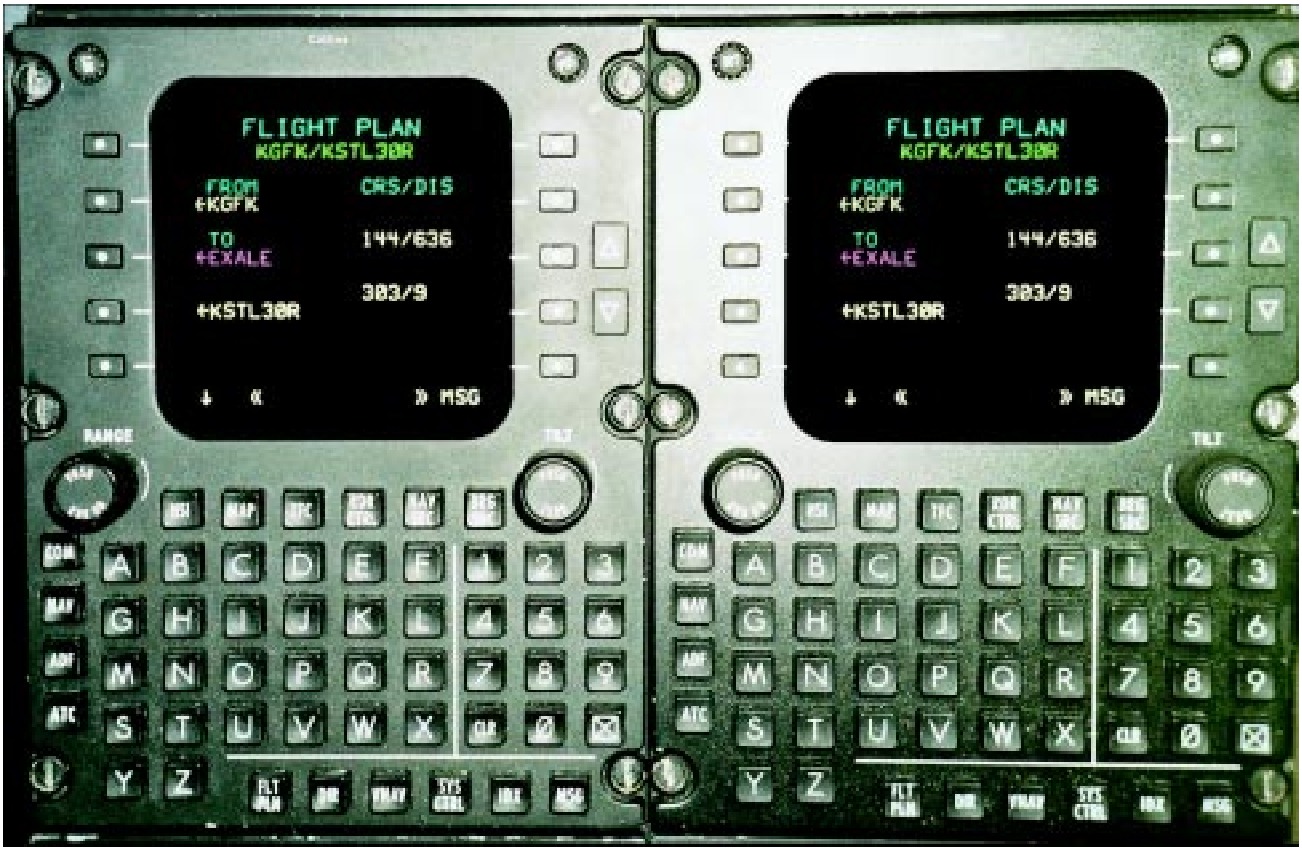


Figure 7-31. *FMS CDU in flight plan mode.*

Once airborne, the FMS computer channels the appropriate NAVAIDs and takes radial/distance information, or channels two NAVAIDs, taking the more accurate distance information. FMS then indicates position, track, desired heading, groundspeed and position relative to desired track. Position information from the FMS updates the INS. In more sophisticated aircraft, the FMS provides inputs to the HSI, RMI, glass cockpit navigation displays, **head-up display (HUD)**, autopilot, and autothrottle systems.

Head-up Display (HUD)

Description

The HUD is a display system that provides a projection of navigation and air data (airspeed in relation to approach reference speed, altitude, left/right and up/down glide slope) on a transparent screen between the pilot and the windshield. Other information may be displayed, including a runway target in relation to the nose of the aircraft. This allows the pilot to see the information necessary to make the approach while also being able to see out the windshield, which diminishes the need to shift between looking at the panel to looking outside. Virtually any information desired can be displayed on the HUD if it is available in the aircraft's flight computer, and if the display is user-definable.

Head-up display (HUD): A special type of flight viewing screen that allows the pilot to watch the flight instruments while looking through the windshield of the aircraft for other traffic, the approach lights, or the runway.

Radar Navigation (Ground Based)

Description

Radar works by transmitting a pulse of RF energy in a specific direction. The return of the echo or bounce of that pulse from a target is precisely timed. From this, the distance traveled by the pulse and its echo is determined and displayed on a radar screen in such a manner that the distance and bearing to this target can be instantly determined. The radar transmitter must be capable of delivering extremely high power levels toward the airspace under surveillance, and the associated radar receiver must be able to detect extremely small signal levels of the returning echoes.

The radar display system provides the controller with a map-like presentation upon which appear all the radar echoes of aircraft within detection range of the radar facility. By means of electronically-generated range marks and azimuth-indicating devices, the controller can locate each radar target with respect to the radar facility, or can locate one radar target with respect to another.

Another device, a video-mapping unit, generates an actual airway or airport map and presents it on the radar display equipment. Using the video-mapping feature, the air traffic controller not only can view the aircraft targets, but will see these targets in relation to runways, navigation aids, and hazardous ground obstructions in the area. Therefore, radar becomes a navigational aid, as well as the most significant means of traffic separation.

In a display presenting perhaps a dozen or more targets, a primary surveillance radar system cannot identify one specific radar target, and it may have difficulty "seeing" a small target at considerable distance—especially if there is a rain shower or thunderstorm between the radar site and the aircraft. This problem is solved with the Air Traffic Control Radar Beacon System (ATCRBS), sometimes called secondary surveillance radar (SSR), which utilizes a transponder in the aircraft. The ground equipment is an interrogating unit, with the beacon antenna mounted so it rotates with the surveillance antenna. The interrogating unit transmits a coded pulse sequence that actuates the aircraft transponder. The transponder answers the coded sequence by transmitting a preselected coded sequence back to the ground equipment, providing a strong return signal and positive aircraft identification, as well as other special data such as the aircraft's altitude.

Functions of Radar Navigation

The radar systems used by ATC are **air route surveillance radar (ARSR)**, **airport surveillance radar (ASR)**, **precision approach radar (PAR)** and **airport surface detection equipment (ASDE)**. Surveillance radars scan through 360° of azimuth and present target information on a radar display located in a tower or center. This information is used independently or in conjunction with other navigational aids in the control of air traffic.

ARSR is a long-range radar system designed primarily to cover large areas and provide a display of aircraft while en route between terminal areas. The ARSR enables air route traffic control center (ARTCC) controllers to provide radar service when the aircraft are within the ARSR coverage. In some instances, ARSR may enable ARTCC to provide terminal radar services similar to but usually more limited than those provided by a radar approach control.

ASR is designed to provide relatively short-range coverage in the general vicinity of an airport and to serve as an expeditious means of handling terminal area traffic through observation of precise aircraft locations on a radarscope. Nonprecision instrument approaches are available at airports that have an approved surveillance radar approach procedure. ASR provides radar vectors to the final approach course, and then azimuth information to the pilot during the approach. Along with range (distance) from the runway, the pilot is advised of MDA, when to begin descent, and when at the MDA. If requested, recommended altitudes will be furnished each mile while on final.

PAR is designed to be used as a landing aid displaying range, azimuth, and elevation information rather than an aid for sequencing and spacing aircraft. PAR equipment may be used as a primary landing aid, or it may be used to monitor other types of approaches. Two antennas are used in the PAR array, one scanning a vertical plane, and the other scanning horizontally. Since the range is limited to 10 miles, azimuth to 20°, and elevation to 7°, only the final approach area is covered. The controller's scope is divided into two parts. The upper half presents altitude and distance information, and the lower half presents azimuth and distance.

The PAR is one in which a controller provides highly accurate navigational guidance in azimuth and elevation to a pilot. Pilots are given headings to fly, to direct them to, and keep their aircraft aligned with the extended centerline of the landing runway. They are told to anticipate glidepath interception approximately 10 to 30 seconds before it occurs

Air route surveillance radar (ARSR): Air route traffic control center (ARTCC) radar used primarily to detect and display an aircraft's position while en route between terminal areas.

Airport surveillance radar (ASR): Approach control radar used to detect and display an aircraft's position in the terminal area.

Precision approach radar (PAR): A specific type and installation of radar, usually found at military or joint-use airfields. It uses two radar antennas, one for left/right information and one for glidepath information to provide a precision approach.

Airport surface detection equipment (ASDE): Radar equipment specifically designed to detect all principle features and traffic on the surface of an airport, presenting the entire image on the control tower console.

and when to start descent. The published decision height (DH) will be given only if the pilot requests it. If the aircraft is observed to deviate above or below the glidepath, the pilot is given the relative amount of deviation by use of terms "slightly" or "well" and is expected to adjust the aircraft's rate of descent/ascent to return to the glidepath. Trend information is also issued with respect to the elevation of the aircraft and may be modified by the terms "rapidly" and "slowly"; e.g., "well above glidepath, coming down rapidly." Range from touchdown is given at least once each mile. If an aircraft is observed by the controller to proceed outside of specified safety zone limits in azimuth and/or elevation and continue to operate outside these prescribed limits, the pilot will be directed to execute a missed approach or to fly a specified course unless the pilot has the runway environment (runway, approach lights, etc.) in sight. Navigational guidance in azimuth and elevation is provided to the pilot until the aircraft reaches the published decision altitude (DA)/DH. Advisory course and glidepath information is furnished by the controller until the aircraft passes over the landing threshold, at which point the pilot is advised of any deviation from the runway centerline. Radar service is automatically terminated upon completion of the approach.

Airport Surface Detection Equipment

Radar equipment is specifically designed to detect all principal features on the surface of an airport, including aircraft and vehicular traffic, and to present the entire image on a radar indicator console in the control tower. It is used to augment visual observation by tower personnel of aircraft and/or vehicular movements on runways and taxiways.

Radar Limitations

1. It is very important for the aviation community to recognize the fact that there are limitations to radar service and that ATC controllers may not always be able to issue traffic advisories concerning aircraft which are not under ATC control and cannot be seen on radar.
2. The characteristics of radio waves are such that they normally travel in a continuous straight line unless they are "bent" by abnormal atmospheric phenomena such as temperature inversions; reflected or attenuated by dense objects such as heavy clouds, precipitation, ground obstacles, mountains, etc.; or screened by high terrain features.
3. Primary radar energy that strikes dense objects will be reflected and displayed on the operator's scope thereby blocking out aircraft at the same range and greatly weakening or completely eliminating the display of targets at a greater range.
4. Relatively low altitude aircraft will not be seen if they are screened by mountains or are below the radar beam due to curvature of the Earth.
5. The amount of reflective surface of an aircraft will determine the size of the radar return. Therefore, a small light airplane or a sleek jet fighter will be more difficult to see on primary radar than a large commercial jet or military bomber.
6. All ARTCC radar in the conterminous U.S. and many airport surveillance radar have the capability to interrogate Mode C and display altitude information to the controller from appropriately equipped aircraft. However, a number of airport surveillance radar do not have Mode C display capability; therefore, altitude information must be obtained from the pilot.