U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: OPERATIONS OF AIRCRAFT AT ALTITUDES ABOVE 25,000 FEET MSL AND/OR MACH NUMBERS (M_{MO}) GREATER THAN .75	**Date: 1/2/03**	**AC No: 61-107A**
	Initiated by: AFS-820	**Change:**

1. PURPOSE. This advisory circular (AC) is issued to alert pilots who are transitioning from aircraft with less performance capability to complex, high-performance aircraft that are capable of operating at high altitudes and high airspeeds, of the need to be knowledgeable about the special physiological and aerodynamic considerations involved in these kinds of operations.

2. CANCELLATION. AC 61-107, Operations of Aircraft at Altitudes Above 25,000 Feet MSL and/or Mach Numbers (Mmo) Greater Than .75, dated January 23, 1991, is cancelled.

3. DEFINITIONS.

a. Aspect Ratio is the relationship between the wing chord and the wingspan. A short wingspan and wide wing chord equal a low aspect ratio.

b. Aileron buzz is a very rapid oscillation of an aileron, at certain critical air speeds of some aircraft, which does not usually reach large magnitudes nor become dangerous. It is often caused by shock-induced separation of the boundary layer.

c. Drag Divergence is a phenomenon that occurs when an airfoil's drag increases sharply and requires substantial increases in power (thrust) to produce further increases in speed. This is not to be confused with MACH crit. The drag increase is due to the unstable formation of shock waves that transform a large amount of energy into heat and into pressure pulses that act to consume a major portion of the available propulsive energy. Turbulent air may produce a resultant increase in the coefficient of drag.

d. Force is generally defined as the cause for motion or of change or stoppage of motion. The ocean of air through which an aircraft must fly has both mass and inertia and, thus, is capable of exerting tremendous forces on an aircraft moving through the atmosphere. When all of the above forces are equal, the aircraft is said to be in a state of equilibrium. For instance, when an aircraft is in level unaccelerated 1 G flight, thrust and drag are equal, and lift and gravity (or weight plus aerodynamic downloads on the aircraft) are equal. Forces that act on any aircraft as the result of air resistance, friction, and other factors are:

(1) **Thrust.** The force required to counteract the forces of drag in order to move an aircraft in forward flight.

(2) **Drag.** The force which acts in opposition to thrust.

(3) **Lift.** The force which sustains the aircraft during flight.

(4) **Gravity.** The force which acts in opposition to lift.

e. MACH, named after Ernst Mach, a 19th century Austrian physicist, is the ratio of an aircraft's true speed as compared to the local speed of sound at a given time or place.

f. MACH Buffet is the airflow separation behind a shock-wave pressure barrier caused by airflow over flight surfaces exceeding the speed of sound.

g. MACH (or Aileron) Buzz is a term used to describe a shock-induced flow separation of the boundary layer air before reaching the ailerons.

h. MACH Meter is an instrument designed to indicate MACH number. MACH indicating capability is incorporated into the airspeed indicator(s) of current generation turbine-powered aircraft capable of MACH range speeds.

i. MACH number is a decimal number (M) representing the true airspeed (TAS) relationship to the local speed of sound (e.g., TAS 75 percent (.75M) of the speed of sound where 100 percent of the speed of sound is represented as MACH 1 (1.0M)). The local speed of sound varies with changes in temperature.

j. MACH number (Critical) is the free stream MACH number at which local sonic flow such as buffet, airflow separation, and shock waves becomes evident. These phenomena occur above the critical MACH number, often referred to as MACH crit. These phenomena are listed as follows:

(1) SUBSONIC MACH Numbers below .75

(2) TRANSONIC MACH Numbers from .75 to 1.20

(3) SUPERSONIC MACH Numbers from 1.20 to 5.0

(4) HYPERSONIC MACH Numbers above 5.0

k. MACH Speed is the ratio or percentage of the TAS to the speed of sound (e.g., 1,120 feet per second (660 Knots (Kts)) at mean sea level (MSL)). This may be represented by MACH number.

l. MACH Tuck is the result of an aftward shift in the center of lift causing a nose down pitching moment.

m. M_{MO} (MACH; maximum operation) is an airplane's maximum certificated MACH number. Any excursion past M_{MO}, whether intentional or accidental, may cause induced flow separation of boundary layer air over the ailerons and elevators of an airplane and result in a loss of control surface authority and/or control surface buzz or snatch.

n. Q-Corner or Coffin Corner is a term used to describe operations at high altitudes where low indicated airspeeds yield high true airspeeds (MACH number) at high angles of attack. The high angle of attack results in flow separation which causes buffet. Turning maneuvers at these altitudes increase the angle of attack and result in stability deterioration with a decrease in control effectiveness. The relationship of stall speed to MACH crit narrows to a point where sudden increases in angle of attack, roll rates, and/or disturbances (e.g., clear air turbulence) cause the limits of the airspeed envelope to be exceeded. Coffin Corner exists in the upper portion of the maneuvering envelope for a given gross weight and G-force.

o. V_{MO} (Velocity maximum operation) is an airplane's indicated airspeed limit. Exceeding V_{MO} may cause aerodynamic flutter and G-load limitations to become critical during dive recovery. Structural design integrity is not predictable at velocities greater than V_{MO}.

4. BACKGROUND. On September 17, 1982, the National Transportation Safety Board (NTSB) issued a series of safety recommendations which included, among other things, that a minimum training curriculum be established for use at pilot schools covering pilots initial transition into general aviation turbojet airplanes. Aerodynamics and physiological aspects of high-performance aircraft operating at high altitudes were among the subjects recommended for inclusion in this training curriculum. These recommendations were the result of an NTSB review of a series of fatal accidents which were believed to involve a lack of flightcrew knowledge and proficiency in general aviation turbojet airplanes capable of operating in a high-altitude environment. Although the near total destruction of physical evidence and the absence of installed flight recorders have inhibited investigators' abilities to pinpoint the circumstances which led to these accidents, the NTSB is concerned that a lack of flightcrew knowledge and proficiency in the subject matter of this AC was involved in either the initial loss of control or the inability to regain control of the aircraft, or both. A requirement has been added to Title 14 of the Code of Federal Regulations (14 CFR) part 61 for high-altitude training of pilots who transition to any pressurized airplane that has a service ceiling or maximum operating altitude, whichever is lower, above 25,000 feet MSL. Recommended training in high altitude operations that would meet the requirements of this regulation can be found in chapter 1, Recommendations for High-Altitude Training. On December 20, 2000, the NTSB issued another series of safety recommendations in response to a Learjet 35 accident on October 25, 1999, which occurred after a prolonged period of pilot incapacitation. This AC is updated to address the NTSB recommendation that the FAA revise existing guidance material concerning time of useful consciousness, hypoxia awareness training.

5. DISCUSSION.

a. Title 14 CFR part 61 prescribes the knowledge and skill requirements for the various airman certificates and ratings, including category, class, and type ratings authorized to be placed thereon. The civil aircraft fleet consists of numerous aircraft capable of high-altitude flight. Certain knowledge elements pertaining to high-altitude flight are essential for the pilots of these aircraft. Pilots who fly in this realm of flight must receive training in the critical factors relating to safe flight operations at high-altitudes. These critical factors include knowledge of the special physiological and/or aerodynamic considerations which should be given to high-performance aircraft operating in the high-altitude environment. High-altitude flight has different effects on the human body than those experienced in lower altitude flight. The aircraft's aerodynamic characteristics in high-altitude flight may differ significantly from those in lower altitude flight.

b. Pilots who are not familiar with operations in the high altitude and high-speed environment are encouraged to obtain thorough and comprehensive training and a checkout in complex high-performance aircraft before engaging in extensive high-speed flight in such aircraft, particularly at high altitudes. The training should enable the pilot to become thoroughly familiar with aircraft performance charts and aircraft systems and procedures. The more critical elements of high-altitude flight planning and operations should also be reviewed. The aircraft checkout should enable the pilot to demonstrate a comprehensive knowledge of the aircraft performance charts, systems, emergency procedures, and operating limitations, along with a high degree of proficiency in performing all flight maneuvers and in-flight emergency procedures. By attaining such knowledge and skill requirements of high-performance aircraft, the pilot's preparedness to transition to the operation of aircraft in the high-speed environment and high-altitude flight, should enhance their awareness on safe and efficient operation.

6. SUMMARY. It is beyond the scope of this AC to provide a more definitive treatment of this subject. This AC serves its purpose if it aids pilots in becoming familiar with the basic phenomena associated with high-altitude and high-speed flight. Pilots should recognize that greater knowledge and skills are needed for the safe and efficient operation of state-of-the-art turbine-powered aircraft at high altitude. Pilots are strongly urged to pursue further study from the many excellent textbooks, charts, and other technical reference materials available through industry sources. From these sources pilots will obtain a detailed understanding of both physiological and aerodynamic factors which relate to the safe and efficient operation of the broad variety of high-altitude aircraft available today and envisioned for the future.

/s/
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CONTENTS

CHAPTER 1. RECOMMENDATIONS FOR HIGH-ALTITUDE TRAINING

CHAPTER 2. MACH FLIGHT AT HIGH ALTITUDES

CHAPTER 1. RECOMMENDATIONS FOR HIGH-ALTITUDE TRAINING

100. PURPOSE. This chapter presents an outline for recommended high-altitude training that meets the requirements of 14 CFR part 61, section 61.31(g). The actual training, which may be derived from this outline, should include both ground and flight training in high-altitude operations. Upon completion of the ground and flight training, the flight instructor who conducted the training should provide an endorsement in the pilot's logbook or training record, certifying that training in high-altitude operations was given. A sample high-altitude endorsement is available in the most recent version of AC 61-65, Certification: Pilots and Flight and Ground Instructors.

a. Although 14 CFR section 61.31(g) applies only to pilots who fly pressurized airplanes with a service ceiling or maximum operating altitude above 25,000 feet MSL, whichever is lower, this training is recommended for all pilots who fly at altitudes above 10,000 feet MSL.

(1) A service ceiling is the maximum height above MSL at which an airplane can maintain a rate of climb of 100 feet per minute under normal conditions.

(2) All pressurized aircraft have a specified maximum operating altitude above which operation is not permitted. This maximum operating altitude is determined by flight, structural, powerplant, functional, or equipment characteristics. An airplane's maximum operating altitude is limited to 25,000 feet or lower, unless certain airworthiness standards are met.

(3) Maximum operating altitudes and service ceilings are specified in the Aircraft Flight Manual (AFM).

b. The training outlined in this chapter is designed primarily for single engine and light twin-engine airplanes that fly at high altitudes but do not require type ratings. The training should, however, be incorporated into type rating courses for aircraft that fly above 25,000 feet MSL if the pilot has not already received training in high-altitude flight. The training in this chapter does not encompass high-speed flight factors such as acceleration, G-forces, MACH, and turbine systems that do not apply to reciprocating engine and turboprop aircraft. Information on high-speed flight can be found in chapter 2, MACH Flight at High Altitudes.

101. OUTLINE. Additional information should be used to complement the training provided herein. The training, which is outlined below and explained in further detail throughout the remainder of this chapter, covers the minimum information needed by pilots to operate safely at high altitudes.

a. Ground Training.

(1) The High Altitude Flight Environment.

(a) Airspace.

(b) Title 14 CFR section 91.211, requirements for use of supplemental oxygen, and the donning of oxygen masks.

(2) Weather.

(a) The atmosphere.

(b) Winds and clear air turbulence.

(c) Clouds and thunderstorms.

(d) Icing.

(3) Flight Planning and Navigation.

(a) Flight planning.

(b) Weather charts.

(c) Navigation.

(d) Navaids.

(4) Physiological Training.

(a) Respiration.

(b) Hypoxia.

(c) Effects of prolonged oxygen use.

(d) Decompression sickness.

(e) Vision.

(f) Altitude chamber (optional).

(5) High Altitude Systems and Components.

(a) Turbochargers.

(b) Oxygen and oxygen equipment.

(c) Pressurization systems.

(d) High-altitude components.

(6) Aerodynamics and Performance Factors.

(a) Acceleration.

(b) G-Forces.

(c) MACH Tuck and MACH Critical.

(7) Emergencies.

(a) Decompressions.

(b) Donning of oxygen masks.

(c) Failure of a mask, or complete loss of oxygen supply/system.

(d) Turbocharger malfunction.

(e) In-flight fire.

(f) Flight into severe turbulence or thunderstorms.

b. Flight Training.

(1) Preflight Briefing.

(2) Preflight Planning.

(a) Weather briefing and considerations.

(b) Course plotting.

(c) Aircraft Flight Manual review.

(d) Flight plan.

(3) Preflight Inspection.

(a) Functional test of the oxygen system, including the verification of supply and pressure, regulator operation, oxygen flow, mask fit, and cockpit and air traffic control (ATC) communication using mask microphones.

(4) Runup, Takeoff, and Initial Climb.

(5) Climb to High Altitude and Normal Cruise Operations While Operating Above 25,000 Feet MSL.

(6) Emergencies.

(a) Simulated rapid decompression, including the immediate donning of oxygen masks.

(b) Emergency descent.

(7) Planned Descents.

(8) Shutdown Procedures.

(9) Postflight Discussion.

102. GROUND TRAINING. Thorough ground training should cover all aspects of high-altitude flight, including the flight environment, weather, flight planning and navigation, physiological aspects of high-altitude flight, the need for the immediate donning of oxygen masks following activation of cabin altitude warning, systems and equipment, aerodynamics and performance, and high-altitude emergencies. The ground training should include the history and causes of some past accidents and incidents involving the topics included in paragraph 101a. Accident reports are available from the NTSB and some aviation organizations.

103. THE HIGH-ALTITUDE FLIGHT ENVIRONMENT. For the purposes of 14 CFR section 61.31(g), flight operations conducted above 25,000 feet are considered high altitude. However, the high-altitude environment itself begins below 25,000 feet. For example, flight levels (FL) are used at and above 18,000 feet (e.g., FL 180) to indicate levels of constant atmospheric pressure in relation to a reference datum of 29.92" Hg. Certain airspace designations and Federal Aviation Administration (FAA) requirements become effective at different altitudes. Pilots must be familiar with these elements before operating in each realm of flight.

a. Airspace. Pilots of high-altitude aircraft are subject to two principle types of airspace at altitudes above 10,000 feet MSL. These are the Class E Airspace which extends from the surface up to FL 180, and the Class A Airspace, which extends from FL 180 to FL 600.

b. Federal Aviation Regulations. In addition to the training required by 14 CFR section 61.31(g), pilots of high-altitude aircraft should be familiar with 14 CFR section 91.211 that applies specifically to flight at high altitudes.

(1) Title 14 CFR section 91.215 requires that all aircraft operating within the continental U.S. at and above 10,000 feet MSL be equipped with an operable transponder with Mode C capability (unless operating at or below 2,500 feet above ground level (AGL).

(2) Title 14 CFR section 91.211(a) requires that the minimum flightcrew on U.S. registered civil aircraft be provided with, and use supplemental oxygen at cabin pressure altitudes above 12,500 feet MSL up to and including 14,000 feet MSL for that portion of the flight that is at those altitudes for more than 30 minutes. The required minimum flightcrew must be provided with and use supplemental oxygen at all times when operating an aircraft above 14,000 feet MSL. At cabin pressure altitudes above 15,000 feet MSL, all occupants of the aircraft must be provided with supplemental oxygen.

(3) Title 14 CFR section 91.211(b) requires pressurized aircraft to have at least a 10-minute additional supply of supplemental oxygen for each occupant at flight altitudes above FL 250 in the event of a decompression. At flight altitudes above FL 350, one pilot at the controls of the airplane must wear and use an oxygen mask that is secured and sealed. The oxygen mask must supply oxygen at all times or must automatically supply oxygen when the cabin pressure altitude of the airplane exceeds 14,000 feet MSL. An exception to this regulation exists for two-pilot crews that operate at or below FL 410. One pilot does not need to wear and use an oxygen mask if both pilots are at the controls and each pilot has a quick donning type of oxygen mask that can be placed on the face with one hand from the ready position and be properly secured, sealed, and operational within 5 seconds. If one pilot of a two-pilot crew is away from the controls, then the pilot that is at the controls must wear and use an oxygen mask that is secured and sealed.

(4) Title 14 CFR section 91.121 requires that aircraft use an altimeter setting of 29.92" Hg at all times when operating at or above FL 180.

(5) Title 14 CFR section 91.135 requires that all flights operating within Class A Airspace be conducted under instrument flight rules (IFR) in an aircraft equipped for IFR and flown by a pilot, who is rated for instrument flight.

(6) Title 14 CFR section 91.159 specifies cruising altitudes and flight levels for visual flight rules (VFR) and IFR flights, respectively. For VFR flights between FL 180 to 290, except within the Class A Airspace where VFR flight is prohibited, odd flight levels plus 500 feet should be flown if the magnetic course is 0° to 179°, and even flight levels plus 500 feet should be flown if the magnetic course is 180° to 359°. VFR flights above FL 290 should be flown at 4,000 foot intervals beginning at FL 300 if the magnetic course is 0° to 179° and FL 320 if the magnetic course is 180° to 359°.

(7) Title 14 CFR section 91.179 specifies IFR flights in uncontrolled airspace between FL 180 and FL 290, odd flight levels should be flown if the magnetic course is 0° to 179°, and even flight levels should be flown if the magnetic course is 180° to 359°. IFR flights in uncontrolled airspace at or above FL 290 should be flown at 4,000 foot intervals beginning at FL 290 if the magnetic course is 0° to 179° and FL 310 if the magnetic course is 180° to 359°. When flying in the Class A Airspace, flight levels assigned by air traffic control (ATC) should be maintained.

104. WEATHER. Pilots should be aware of and recognize the meteorological phenomena associated with high altitudes and the effects of these phenomena on flight.

a. The Atmosphere. The atmosphere is a mixture of gases in constant motion. It is composed of approximately 78 percent nitrogen, 21 percent oxygen, and 1 percent other gases. Water vapor is constantly being absorbed and released in the atmosphere which causes changes in weather. The three levels of the atmosphere where high-altitude flight may occur are the troposphere, which can extend from sea level to approximately FL 350 around the poles and up to FL 650 around the equator; tropopause, a thin layer at the top of the troposphere that traps water vapor in the lower level; and stratosphere, which extends from the tropopause to approximately 22 miles. The stratosphere is characterized by lack of moisture and a constant temperature of -55° C, while the temperature in the troposphere decreases at a rate of 2° C per 1,000 feet. Condensation trails, or contrails, are common in the upper levels of the troposphere and in the stratosphere. These cloud-like streamers that are generated in the wake of aircraft flying in clear, cold, humid air, form by water vapor from aircraft exhaust gases being added to the atmosphere causing saturation or supersaturation of the air. Contrails can also form aerodynamically by the pressure reduction around airfoils, engine nacelles, and propellers cooling the air to saturation.

b. Atmospheric density in the troposphere decreases 50 percent at 18,000 feet. This means that at FL 180, the air contains only one-half the oxygen molecules as at sea level. Because the human body requires a certain amount of oxygen for survival, aircraft that fly at high altitudes must be equipped with some means of creating an artificial atmosphere, such as cabin pressurization.

c. Winds.

(1) The jet stream is a narrow band of high-altitude winds, near or in the tropopause, that results from large temperature contrasts over a short distance (typically along fronts) creating large pressure gradients aloft. The jet stream usually travels in an easterly direction between 50 and 200 Kts. The speed of the jet stream is greater in the winter than in the summer months because of greater temperature differences. It generally drops more rapidly on the polar side than on the equatorial side. In the mid-latitudes, the Polar Front Jet Stream is found in association with the Polar Front. This jet stream has a variable path, sometimes flowing almost due North and South.

(2) Because of its meandering path, the Polar Front Jet Stream is not found on most circulation charts. One almost permanent jet is a westerly jet found over the subtropics at 25° latitude about 8 miles (42,200 ft) above the surface. Low pressure systems usually form to the south of the jet stream and move northward until they become occluded lows which move north of the jet stream. Horizontal windshear and turbulence are frequently found on the northern side of the jet stream.

d. Clear Air Turbulence (CAT). CAT is a meteorological phenomenon associated with high-altitude winds. This high-level turbulence occurs where no clouds are present and can take place at any altitude (normally above 15,000 feet AGL), although it usually develops in or near the jet stream where there is a rapid change in temperature. CAT is generally stronger on the polar side of the jet and is greatest during the winter months. CAT can be caused by wind shear, convection currents, mountain waves, strong low pressures aloft, or other obstructions to normal wind flow. CAT is difficult to forecast because it gives no visual warning of its presence and winds can carry it far from its point of origin.

e. Clouds and Thunderstorms.

(1) Cirrus and cirriform clouds are high-altitude clouds that are composed of ice crystals. Cirrus clouds are found in stable air above 30,000 feet in patches or narrow bands. Cirriform clouds, such as the white clouds in long bands against a blue background known as cirrostratus clouds, generally indicate some type of system below. Cirrostratus clouds form in stable air as a result of shallow convection currents and also may produce light turbulence. Clouds with extensive vertical development (e.g., towering cumulus and cumulonimbus clouds) indicate a deep layer of unstable air and contain moderate to heavy turbulence with icing. The bases of these clouds are found at altitudes associated with low to middle clouds but their tops can extend up to 60,000 feet or more.

(2) Cumulonimbus clouds are thunderstorm clouds that present a particularly severe hazard to pilots and should be circumnavigated if possible. Hazards associated with cumulonimbus clouds include embedded thunderstorms, severe or extreme turbulence, lightning, icing, and dangerously strong winds and updrafts.

f. Icing. Icing at high altitudes is not as common or extreme as it can be at low altitudes. When it does occur, the rate of accumulation at high altitudes is generally slower than at low altitudes. Rime ice is generally more common at high altitudes than clear ice, although clear ice is possible. Despite the composition of cirrus clouds, severe icing is generally not a problem although it can occur in some detached cirrus. It is more common in tops of tall cumulus buildups, anvils, and over mountainous regions. Many airplanes that operate above 25,000 feet are equipped with deice or anti-ice systems, reducing even further the dangers of icing.

105. FLIGHT PLANNING AND NAVIGATION.

a. Flight Planning.

(1) Careful flight planning is critical to safe high-altitude flight. Consideration must be given to power settings, particularly on takeoff, climb, and descent to assure operation in accordance with the manufacturer's recommendations. Fuel management, reporting points, weather briefings (not only thunderstorms, the freezing level, and icing at altitude but at all levels and destinations,

including alternates, that may affect the flight), direction of flight, airplane performance charts, high speed winds aloft, and oxygen duration charts must also be considered. When possible, additional oxygen should be provided to allow for emergency situations. Breathing rates increase under stress and extra oxygen could be necessary.

(2) Flight planning should take into consideration factors associated with altitudes that will be transited while climbing to or descending from the high altitudes (e.g., airspeed limitations below 10,000 feet MSL, airspace, and minimum altitudes). Westward flights should generally be made away from the jet stream to avoid the strong headwind, and eastward flights should be made in the jet stream when possible to increase ground speed. Ground speed checks are particularly important in high-altitude flight. If fuel runs low because of headwinds or poor flight planning, a decision to fly to an alternate airport should be made as early as possible to allow time to re-plan descents and advise ATC.

b. Knowledge of Aircraft. Complete familiarity with the aircraft systems and limitations is extremely important. For example, many high-altitude airplanes feed from only one fuel tank at a time. If this is the case, it is important to know the fuel consumption rate to know when to change tanks. This knowledge should be made part of the preflight planning and its accuracy confirmed regularly during the flight.

c. Gradual Descents. Gradual descents from high altitudes should be planned in advance to prevent excessive engine cooling and provide passenger comfort. The manufacturer's recommendations found in the AFM should be complied with, especially regarding descent power settings to avoid stress on the engines. Although most jets can descend rapidly at idle power, many turboprop and light twin airplanes require some power to avoid excessive engine cooling, cold shock, and metal fatigue. ATC does not always take aircraft type into consideration when issuing descent instructions. It is the pilot's responsibility to fly the airplane in the safest manner possible. Cabin rates of descent are particularly important and should generally not exceed 500 or 600 feet per minute. Before landing, cabin pressure should be equal to ambient pressure or inner ear injury can result. If delays occur en route, descents should be adjusted accordingly.

d. Weather Charts. Before beginning a high-altitude flight, all weather charts should be consulted, including those designed for low levels. Although high-altitude flight may allow a pilot to over-fly adverse weather, low altitudes must be transited on arrival, departure, and in an emergency situation that may require landing at any point en route.

e. Types of Weather Charts. Weather charts that provide information on high-altitude weather include Constant Pressure charts which provide information on pressure systems, temperature, winds, and temperature/dewpoint spread at the 850 millibar (mb), 700 mb, 500 mb, 300 mb, and 200 mb levels (5 charts are issued every 12 hours). Prognostic Charts forecast winds, temperature, and expected movement of weather over the 6-hour valid time of the chart. Observed Tropopause Charts provide jet stream, turbulence, and temperature-wind-pressure reports at the tropopause over each station. Tropopause Wind Prognostic Charts and Tropopause Height Vertical Wind Shear Charts are helpful in determining jet stream patterns and the presence of CAT and wind shear.

f. Wind Shear. Wind shear is indicated by dashed lines on Tropopause Height Vertical Wind shear Charts. Horizontal wind changes of 40 Kts within 150 NM, or vertical wind shear of 6 Kts or greater per 1,000 feet usually indicate moderate to severe turbulence and should be avoided. Pilot reports (PIREP) are one of the best methods of receiving timely and accurate reports on icing and turbulence at high altitudes.

g. Navigation. Specific charts have been designed for flight at FL 180 and above. En route high-altitude charts delineate the jet route system, which consists of routes established from FL 180 up to and including FL 450. The VOR airways established below FL 180 found on low-altitude charts must not be used at FL 180 and above. High-altitude jet routes are an independent matrix of airways, and pilots must possess the appropriate en route high-altitude charts before transitioning to the flight levels.

h. Jet Routes. Jet routes in the U.S. are predicated solely on VOR or VORTAC navigation facilities, except in Alaska where some are based on Low/Medium Frequency navigation aids. All jet routes are identified by the letter "J" followed by the airway number.

i. Reporting Points. Reporting points are designated for jet route systems and must be used by flights using the jet route unless otherwise advised by ATC. Flights above FL 450 may be conducted on a point-to-point basis, using the facilities depicted on the en route high-altitude chart as navigational guidance. Area Navigation (RNAV) routes, using either random or fixed way points, are also used for direct navigation at high altitudes. These routes are based on area navigation capability between way points defined in terms of latitude/longitude coordinates, degree-distance fixes, or offsets from established routes or airways at a specified distance and direction. Radar monitoring by ATC is required on all random RNAV routes.

j. Navaids. VOR, DME, and TACAN depicted on high-altitude charts are designated as class H navaids, signifying that their standard service volume is from 1,000 feet AGL up to and including 14,500 feet AGL at radial distances out to 40 NM; from 14,500 feet AGL up to and including 60,000 feet AGL at radial distances out to 100 NM; and from 18,000 feet AGL up to and including 45,000 feet AGL at radial distances out to 130 NM. Ranges of NDB service volumes are the same at all altitudes.

106. PHYSIOLOGICAL TRAINING. To ensure safe flights at high altitudes, pilots of high-altitude aircraft must understand the physiological effects of high-altitude flight and the effect of hypoxia on an individual's ability to perform complex tasks in a changing environment. Additional physiological training information, including locations and application procedures for attending an altitude chamber, can be found in paragraph 107, Additional Physiological Training. Although not required, altitude chamber training is highly recommended for all pilots.

a. Respiration is the exchange of gases between the organism and its environment. In humans, external respiration is the intake of oxygen from the atmosphere by the lungs and the elimination of some carbon dioxide from the body into the surrounding atmosphere. Each breath intake is comprised of approximately 21 percent oxygen, which is absorbed into the bloodstream and carried by the blood throughout the body to burn food material and to produce heat and kinetic energy. The partial pressure of oxygen forces oxygen through air sacs (alveoli), located at the end of each of the smaller tubes that branches out from the bronchial tubes and lungs, into the bloodstream. Other gases contained in the lungs reduce the partial pressure of oxygen entering the air sacs to about 102 mm Hg at ground level, which is approximately 21 percent of the total atmospheric pressure.

b. The human body functions normally in the atmospheric area extending from sea level to 12,000 feet MSL. In this range, brain oxygen saturation is at a level that allows for normal functioning. (Optimal functioning is 96 percent saturation. At 12,000 feet, brain oxygen saturation is approximately 87 percent which begins to approach a level that could affect human performance. Although oxygen is not required below 12,500 feet MSL, its use is recommended when flying above 10,000 feet MSL during the day and above 5,000 feet MSL at night when the eyes become more sensitive to oxygen deprivation.)

c. Although minor physiological problems, such as middle ear and sinus trapped gas difficulties, can occur when flying below 12,000 feet, shortness of breath, dizziness, and headaches will result when an individual ascends to an altitude higher than that to which his or her body is acclimated. From 12,000 to 50,000 feet MSL, atmospheric pressure drops by 396 mm Hg. This area contains less partial pressure of oxygen which can result in problems such as trapped or evolved gases within the body. Flight at and above 50,000 feet MSL requires sealed cabins or pressure suits.

d. Hypoxia is a lack of sufficient oxygen in the body cells or tissues caused by an inadequate supply of oxygen, inadequate transportation of oxygen, or inability of the body tissues to use oxygen. A common misconception among many pilots who are inexperienced in high-altitude flight operations and who have not been exposed to physiological training is that it is possible to recognize the symptoms of hypoxia and to take corrective action before becoming seriously impaired. While this concept may be appealing in theory, it is both misleading and dangerous for an untrained crewmember. Symptoms of hypoxia vary from pilot to pilot, but one of the earliest effects of hypoxia is impairment of judgment. Other symptoms can include one or more of the following:

(1) Behavioral changes (e.g., a sense of euphoria).

(2) Poor coordination.

(3) Discoloration at the fingernail beds (cyanosis).

(4) Sweating.

(5) Increased breathing rate, headache, sleepiness, or fatigue.

(6) Loss or deterioration of vision.

(7) Light-headedness or dizzy sensations and listlessness.

(8) Tingling or warm sensations.

e. While other significant effects of hypoxia usually do not occur in a healthy pilot in an un-pressurized aircraft below 12,000 feet, there is no assurance that this will always be the case. The onset of hypoxic symptoms may seriously affect the safety of flight and may well occur even in short periods of exposure to altitudes from 12,000 to 15,000 feet. The ability to take corrective measures may be totally lost in 5 minutes at 22,000 feet. However, that time would be reduced to only 7 to 10 seconds at 40,000 feet and the crewmember may suffer total loss of consciousness soon thereafter. A description of the four major hypoxia groups and the recommended methods to combat each follows.

(1) **Hypoxic (Altitude) Hypoxia.** Altitude hypoxia poses the greatest potential physiological hazard to a flight crewmember while flying in the high-altitude environment. This type of hypoxia is caused by an insufficient partial pressure of oxygen in the inhaled air resulting from reduced oxygen pressure in the atmosphere at altitude. If a person is able to recognize the onset of hypoxic symptoms, immediate use of supplemental oxygen will combat hypoxic hypoxia within seconds. Oxygen systems should be checked periodically to ensure that there is an adequate supply of oxygen and that the system is functioning properly. This check should be performed frequently with increasing altitude. If supplemental oxygen is not available, an emergency descent to an altitude below 10,000 feet should be initiated.

(2) **Histotoxic Hypoxia.** This is the inability of the body cells to use oxygen because of impaired cellular respiration. This type of hypoxia, caused by alcohol or drug use, cannot be corrected by using supplemental oxygen because the uptake of oxygen is impaired at the tissue level. The only method of avoiding this type of hypoxia is to abstain, before flight, from alcohol or drugs that are not approved by a flight surgeon or an aviation medical examiner.

(3) **Hypemic (Anemic) Hypoxia.** This type of hypoxia is defined as a reduction in the oxygen-carrying capacity of the blood. Hypemic hypoxia is caused by a reduction in circulating red blood cells (hemoglobin) or contamination of blood with gases other than oxygen as a result of anemia, carbon monoxide poisoning, or excessive smoking. Pilots should take into consideration the effect of smoking on altitude tolerance when determining appropriate cabin pressures. If heavy smokers are among the crew or passengers, a lower cabin altitude should be set because apparent altitudes for smokers are generally much higher than actual altitudes. For example, a smoker's apparent altitude at sea level is approximately 7,000 feet. Twenty thousand feet actual altitude for a nonsmoker would be equivalent to an apparent altitude of 22,000 feet for a smoker. The smoker is thus more susceptible to hypoxia at lower altitudes than the nonsmoker. Hypemic hypoxia is corrected by locating and eliminating the source of the contaminating gases. A careful preflight of heating systems and exhaust manifold equipment is mandatory. Also, cutting down on smoking would minimize the onset of this type of hypoxia. If symptoms are recognized, initiate use of supplemental oxygen and/or descend to an altitude below 10,000 feet. If symptoms persist, ventilate the cabin and land as soon as possible because the symptoms may be indicative of carbon monoxide poisoning and medical attention should be sought.

(4) **Stagnant Hypoxia.** This is an oxygen deficiency in the body resulting from poor circulation of the blood because of a failure of the circulatory system to pump blood (and oxygen) to the tissues. Evidence of coronary artery disease is grounds for immediate denial or revocation of a medical certificate. In flight, this type of hypoxia can sometimes be caused by positive pressure breathing for long periods of time or excessive G-forces.

f. Effective Performance Time (EPT) or Time of Useful Consciousness (TUC) is the amount of time in which a person is able to effectively or adequately perform flight duties with an insufficient supply of oxygen. EPT decreases with altitude, until eventually coinciding with the time it takes for blood to circulate from the lungs to the head usually at an altitude above 35,000 feet. Table 1-1 shows the TUC (shown as average TUC) at various altitudes. The rate of ascent directly affects TUC. Faster rates of ascent result in shorter TUC.

TABLE 1-1. TIMES OF USEFUL CONSCIOUSNESS AT VARIOUS ALTITUDES

	Standard Ascent Rate	After Rapid Decompression
Altitude (Feet)	Time	Time
18,000	20 to 30 minutes	10 to 15 minutes
22,000	10 minutes	5 minutes
25,000	3 to 5 minutes	1.5 to 3.5 minutes
28,000	2.5 to 3 minutes	1.25 to 1.5 minutes
30,000	1 to 2 minutes	30 to 60 seconds
35,000	30 to 60 seconds	15 to 30 seconds
40,000	15 to 20 seconds	7 to 10 seconds
43,000	9 to 12 seconds	5 seconds
50,000	9 to 12 seconds	5 seconds

g. Other factors that determine EPT are physical activities (exercise decreases EPTs), and day-to-day factors such as physical fitness, diet, rest, prescription drugs, smoking, and illness. Altitude chamber experiments found a significantly longer TUC for nonsmoker pilots who exercise and watch their diet than for pilots who smoke and are not physically fit.

h. Prolonged oxygen use can also be harmful to human health. One hundred percent aviation oxygen can produce toxic symptoms if used for extended periods of time. The symptoms can consist of bronchial cough, fever, vomiting, nervousness, irregular heart beat, and lowered energy. These symptoms appeared on the second day of breathing 90 percent oxygen during controlled experiments. It is unlikely that oxygen would be used long enough to produce the most severe of these symptoms in any aviation incidence. However, prolonged flights at high altitudes using a high concentration of oxygen can produce some symptoms of oxygen poisoning such as infection or bronchial irritation. The sudden supply of pure oxygen following a decompression can often aggravate the symptoms of hypoxia. Therefore, oxygen should be taken gradually, particularly when the body is already suffering from lack of oxygen, to build up the supply in small doses. If symptoms of oxygen poisoning develop, high concentrations of oxygen should be avoided until the symptoms completely disappear.

i. When nitrogen is inhaled, it dilutes the air we breathe. While most nitrogen is exhaled from the lungs along with carbon dioxide, some nitrogen is absorbed by the body. The nitrogen absorbed into the body tissues does not normally present any problem because it is carried in a liquid state. If the ambient surrounding atmospheric pressure lowers drastically, this nitrogen could change from a liquid and return to its gaseous state in the form of bubbles. These evolving and expanding gases in the body are known as decompression sickness and are divided into two groups.

(1) **Trapped Gas.** Expanding or contracting gas in certain body cavities during altitude changes can result in abdominal pain, toothache, or pain in ears and sinuses if the person is unable to equalize the pressure changes. Above 25,000 feet, distention can produce particularly severe gastrointestinal pain.

(2) **Evolved Gas.** When the pressure on the body drops sufficiently, nitrogen comes out of solution and forms bubbles which can have adverse effects on some body tissues. Fatty tissue

contains more nitrogen than other tissue; thus making overweight people more susceptible to evolved gas decompression sicknesses.

(a) SCUBA diving will compound this problem because of the compressed air used in the breathing tanks. After SCUBA diving, a person who flies in an aircraft to a pressure altitude of 8,000 feet would experience the same effects as a non-diver flying at 40,000 feet un-pressurized. The recommended waiting period before going to flight altitudes of 8,000 feet is at least 12 hours after non-decompression stop diving (diving which does not require a controlled ascent), and 24 hours after decompression stop diving (diving which requires a controlled ascent). For flight altitudes above 8,000 feet, the recommended waiting time is at least 24 hours after any SCUBA diving. (See Airman's Information Manual (AIM) paragraph 8-1-2 (d) (2).)

(b) The bends, also known as caisson disease, is one type of evolved gas decompression sickness and is characterized by pain in and around the joints. The pain gradually becomes more severe, can eventually become temporarily incapacitating, and can result in collapse. The chokes refers to a decompression sickness that manifests itself through chest pains and burning sensations, a desire to cough, possible cyanosis, a sensation of suffocation, progressively shallower breathing and, if a descent is not made immediately, collapse and unconsciousness. Paresthesia is a third type of decompression sickness, characterized by tingling, itching, a red rash, and cold and warm sensations, probably resulting from bubbles in the central nervous system (CNS). CNS disturbances can result in visual deficiencies such as illusionary lines or spots, or a blurred field of vision. Some other effects of CNS disturbances are temporary partial paralysis, sensory disorders, slurred speech, and seizures.

j. Shock can often result from decompression sicknesses as a form of body protest to disrupted circulation. Shock can cause nausea, fainting, dizziness, sweating, and/or loss of consciousness. The best treatment for decompression sickness is descent to a lower altitude and landing. If conditions persist after landing, recompression chambers can be located through an aviation medical examiner.

k. Vision has a tendency to deteriorate with altitude. A reversal of light distribution at high altitudes (bright clouds below the airplane and darker, blue sky above) can cause a glare inside the cockpit. Glare effects and deteriorated vision are enhanced at night when the body becomes more susceptible to hypoxia and can occur at altitudes as low as 5,000 feet. In addition, the empty visual field caused by cloudless, blue skies during the day can cause inaccuracies when judging the speed, size, and distance of other aircraft. Sunglasses are recommended to minimize the intensity of the sun's ultraviolet rays at high altitudes.

107. ADDITIONAL PHYSIOLOGICAL TRAINING. There are no specific requirements in 14 CFR part 91 or 125 for physiological training. However, in addition to the high-altitude training required by 14 CFR section 61.31(g), which should include the physiological training outlined in this chapter, 14 CFR parts 121 and 135 require flight crewmembers that serve in operations above 25,000 feet to receive training in specified subjects of aviation physiology. None of the requirements includes altitude chamber training. The U.S. military services require its flight crewmembers to complete both initial and refresher physiological training, including instruction in basic aviation physiology and altitude chamber training. Other U.S. Government agencies, such as the National Aeronautics and Space Administration and FAA, also require their flight personnel who operate pressurized aircraft in the high-altitude flight environment to complete similar training. Although most of the subject material normally covered in physiological training concerns problems associated with reduced atmospheric pressure at high-flight altitudes, other equally important subjects are covered as well. Such subjects of aviation physiology as vision, disorientation, physical fitness, stress, and survival affect flight safety and are normally presented in a good training program. The FAA Civil Aerospace Medical Institute (CAMI) offers a one-day aviation physiology course for FAA flightcrews, civil aviation pilots, and FAA aviation medical examiners (AME). In addition to the basic academic contents, this course offers practical demonstrations of rapid decompression (8 to 18,000 feet) and hypoxia (25,000 feet) in a hypobaric chamber, as well as a practical demonstration of spatial disorientation in a Vertigon or the new General Aviation Spatial Disorientation Demonstrator (Gyro-1).

a. Physiological training programs are offered at locations across the U.S. (table 1-2) for civil pilots at U.S. Air Force physiology training units under the USAF/FAA physiological Training Agreement. Trainees who attend these programs will receive classroom lectures and learn to recognize and overcome vertigo, hypoxia, hyperventilation, etc., during flight, and a high-altitude flight in an altitude chamber. The U.S. Army and the FAA are currently working on the development of a similar joint training program.

b. Persons who wish to take this training must be at least 18 years of age, hold a current FAA Airman Medical Certificate, and must not have a cold or any other significant health problem when enrolling for the course.

NOTE: Anyone can attend the training regardless of whether they are a pilot or not. However, they are still required to obtain a minimum of a class III medical certificate in order to participate in the altitude chamber training.

c. Scheduling. CAMI's Airman Education Programs obtains a list of training dates from each base that are available to anyone interested in the training. These dates can be accessed by calling 405-954-4837. To schedule a training slot the following information will be required for each student:

(1) Pilot certificate number or social security number

(2) Last name

(3) First name

(4) Middle initial

(5) Date of birth

(6) Mailing address

(7) Daytime phone number

(8) Date of FAA medical

(9) The class of the medical the day it was issued.

d. Submitting an Application. Once you have been assigned a training date, CAMI will mail an application and a notification letter to you. The application must be completed and mailed to the address provided within 30 days of the scheduled training, along with the fee, made payable to the FAA. The applicant should take the notification letter, along with a current medical certificate, to the base, the day of the training. Effective August 13, 2001, the course fee of $50.00 is non-refundable and not transferable.

TABLE 1-2. TRAINING LOCATIONS

Andrews AFB, MD	Fort Rucker (Army), AL	Offut AFB, NE
Beale AFB, CA	Holloman AFB, NM	Peterson AFB, CO
Brooks AFB, TX	Langley AFB, VA	Randolph AFB, TX
Columbus AFB, MS	Laughlin AFB, TX	Shaw AFB, SC
Fairchild AFB, WA	Little Rock AFB, AR	Vance AFB, OK

108. HIGH-ALTITUDE SYSTEMS AND EQUIPMENT. Several systems and equipment are unique to aircraft that fly at high altitudes, and pilots should be familiar with their operation before using them. Before any flight, a pilot should be familiar with all the systems on the aircraft to be flown.

a. Turbochargers. Most light piston engine airplanes that fly above 25,000 feet MSL are turbocharged. Turbochargers compress air in the carburetor or cylinder intake by using exhaust gases from an engine-driven turbine wheel. The increased air density provides greater power and improved performance. Light aircraft use one of two types of turbocharge systems.

(1) The first is the normalized system, which allows the engine to develop sea level pressure from approximately 29 inches of manifold pressure up to a critical altitude (generally between 14,000 to 16,000 feet MSL).

(2) The second is the supercharger system, which is a more powerful system that allows the engine to develop higher than sea level pressure (up to 60 inches of manifold pressure) up to a critical altitude. To prevent overboosting at altitudes below the critical altitude, a waste gate is installed in the turbocompressor system to release unnecessary gases. The waste gate is a damper-like device that controls the amount of exhaust that strikes the turbine rotor. As the waste gate closes with altitude, it sends more gases through the turbine compressor causing the rotor to spin faster. This allows the engine to function as if it were maintaining sea level or, in the case of a supercharger, above sea level manifold pressure. The three principle types of waste gate operations are manual, fixed, and automatic.

(a) **Manual Waste Gate.** Manual waste gate systems are common in older aircraft but have been discontinued due to the additional burden on the pilot. Waste gates were often left closed on takeoff, resulting in an overboost that could harm the engine.

(b) **Fixed Waste Gate.** Fixed waste gates pose less of a burden on the pilot, but the pilot must still be careful not to overboost the engine, especially on takeoff, initial climb, and on cold days when the air is especially dense. This type of waste gate remains in the same position during all engine operations, but it splits the exhaust flow allowing only partial exhaust access to the turbine. The pilot simply controls manifold pressure with smooth, slow application of the throttle to control against overboost. If overboost does occur, a relief valve on the intake manifold protects the engine from damage. This is not a favorable system due to fluctuations in manifold pressure and limited additional power from the restricted control over the exhaust flow. In addition, the compressor can produce excessive pressure and cause overheating.

(c) **Automatic Waste Gate.** Automatic waste gates operate on internal pressure. When internal pressure builds towards an overboost, the waste gate opens to relieve pressure, keeping the engine within normal operating limits regardless of the air density.

1 The pressure-reference automatic waste gate system maintains the manifold pressure set by the throttle. Engine oil pressure moves the waste gate to maintain the appropriate manifold pressure, thus reducing the pilot's workload and eliminating the possibility of overboost. If the airplane engine is started up and followed by an immediate takeoff, cold oil may cause a higher than intended manifold pressure. Allow the oil to warm up and circulate throughout the system before takeoff.

2 The density-reference waste gate system is controlled by compressor discharge air. A density controller holds a given density of air by automatically adjusting manifold pressure as airspeed, ambient pressure, temperature, altitude, and other variables change.

b. Turbocharged engines are particularly temperature sensitive. Manufacturers often recommend increasing the fuel flow during climbs to prevent overheating. It is also important to cool the engine after landing. Allowing the engine to idle for approximately one minute before shutting it down permits engine oil to flow through the system, cooling the engine while simultaneously cooling and lubricating the turbocharger.

c. Most high-altitude airplanes come equipped with some type of fixed oxygen installation. If the airplane does not have a fixed installation, portable oxygen equipment must be readily accessible during flight. The portable equipment usually consists of a container, regulator, mask outlet, and pressure gauge. A typical 22 cubic-foot portable container will allow four people enough oxygen to last approximately 1.5 hours at 18,000 feet MSL. Aircraft oxygen is usually stored in high-pressure system containers of 1,800-2,200 pounds per square inch (PSI). The container should be fastened securely in the aircraft before flight. When the ambient temperature surrounding an oxygen cylinder decreases, pressure within that cylinder will decrease because pressure varies directly with temperature if the volume of a gas remains constant. Therefore, if a drop in indicated pressure on a supplemental oxygen cylinder is noted, there is no reason to suspect depletion of the oxygen supply, which has simply been compacted due to storage of the containers in an unheated area of the aircraft. High pressure oxygen containers should be marked with the PSI tolerance (i.e., 1,800 PSI) before filling the container to that pressure. The containers should be supplied with aviation oxygen only, which is 100 percent pure oxygen. Industrial oxygen is not intended for breathing and may contain impurities, and medical oxygen contains water vapor that can freeze in the regulator when exposed to cold temperatures. To assure safety, oxygen system periodic inspection and servicing should be done at FAA certificated stations found at some fixed base operations and terminal complexes.

d. Regulators and masks work on continuous flow, diluter demand, or on pressure demand systems. The continuous flow system supplies oxygen at a rate that may either be controlled by the user or controlled automatically on some regulators. The mask is designed so the oxygen can be diluted with ambient air by allowing the user to exhale around the face piece, and comes with a rebreather bag which allows the individual to reuse part of the exhaled oxygen. Pilot masks sometimes allow greater oxygen flow than passengers' masks, so it is important that pilots use the masks that are indicated for them. Although certificated up to 41,000 feet, very careful attention to system capabilities is required when using continuous flow oxygen systems above 25,000 feet.

e. Diluter demand and pressure demand systems supply oxygen only when the user inhales through the mask. An automix lever allows the regulators to automatically mix cabin air and oxygen or supply 100 percent oxygen, depending on the altitude. The demand mask provides a tight seal over the face to prevent dilution with outside air and can be used safely up to 40,000 feet. Pilots who fly at those altitudes should not have beards and moustaches because air can easily seep in through the border of the mask. Pressure demand regulators also create airtight and oxygen-tight seals but they also provide a positive pressure application of oxygen to the mask face-piece which allows the user's lungs to be pressurized with oxygen. This feature makes pressure demand regulators safe at altitudes above 40,000 feet.

f. Pilots should be aware of the danger of fire when using oxygen. Materials that are nearly fireproof in ordinary air may be susceptible to burning in oxygen. Oils and greases may catch fire if exposed to oxygen and, therefore, cannot be used for sealing the valves and fittings of oxygen equipment. Smoking during any kind of oxygen equipment use must also be strictly forbidden.

g. Surplus oxygen equipment must be inspected and approved by a certified FAA inspection station before use. Before each flight, the pilot should thoroughly inspect and test all oxygen equipment. The inspection should be accomplished with clean hands and should include a visual inspection of the mask and tubing for tears, cracks, or deterioration; the regulator for valve and lever condition and positions; oxygen quantity; and the location and functioning of oxygen pressure gauges, flow indicators, and connections. The mask should be donned and the system should be tested. After any oxygen use, verify that all components and valves are shut off.

h. Cabin pressurization is the compression of air in the aircraft cabin in order to maintain a cabin altitude lower than the actual flight altitude. Because of the ever-present possibility of decompression, supplemental oxygen is still required. Pressurized aircraft meeting specific requirements of 14 CFR part 23 or 25 have cabin altitude warning systems which are activated at 10,000 feet. Pressurized aircraft meeting the still more stringent requirements of 14 CFR part 25 have automatic passenger oxygen mask dispensing devices which activate before exceeding 15,000 feet cabin altitude.

i. Pressurization in most light aircraft is sent to the cabin from the turbocharger's compressor or from an engine-driven pneumatic pump. The flow of compressed air into the cabin is regulated by an outflow valve which keeps the pressure constant by releasing excess pressure into the atmosphere. The cabin altitude can be manually selected and is monitored by a gauge which indicates the pressure difference between the cabin and ambient altitudes. The rate of change between these two pressures is automatically controlled with a manual backup control.

j. Each pressurized aircraft has a determined maximum pressure differential, which is the maximum differential between cabin and ambient altitudes that the pressurized section of the aircraft can support. The pilot must be familiar with these limitations, as well as the manifold pressure settings recommended for various pressure differentials. Some aircraft have a negative pressure relief valve to equalize pressure in the event of a sudden decompression or rapid descent to prevent the cabin pressure from becoming higher than the ambient pressure.

k. Reducing exposure to low barometric pressure lowers the occurrence of decompression sickness and the need for an oxygen mask is eliminated as a full-time oxygen source above certain altitudes. Many airplanes are equipped with automatic visual and aural warning systems that indicate an unintentional loss of pressure.

l. Technology is continuously improving flight at high altitudes through the development of new devices and the improvement of existing systems. One such example is the pressurized magneto. Thin air at high altitudes makes the unpressurized magneto susceptible to crossfiring. The high tension pressurized system is composed of sealed caps and plugs that keep the electrodes contained within the body. A pressure line extends directly from the turbodischarger to the magneto. Pressurized magnetos perform better at high altitudes where low pressure and cold atmosphere have a detrimental effect on electrical conductivity. Flight above 14,000 feet with an unpressurized magneto should be avoided because of its higher susceptibility to arcing.

m. Another airplane component recommended for flight at high altitudes is the dry vacuum pump. Engine-driven wet vacuum pumps cannot create a sufficient vacuum to drive the gyros in the low air density found at high altitudes. Furthermore, gyros and rubber deicing boots can be ruined by oil contamination from the wet pump system, which uses engine oil for lubrication and cooling. Dry vacuum pumps are lightweight, self-lubricating systems that eliminate oil contamination and cooling problems. These pumps can power either a vacuum or pressure pneumatic system, allowing them to drive the gyros, deice boots, and pressurize the door seals.

109. AERODYNAMICS AND PERFORMANCE FACTORS. Thinner air at high altitudes has a significant impact on an airplane's flying characteristics because surface control effects, lift, thrust, drag, and horsepower are all functions of air density.

a. The reduced weight of air moving over control surfaces at high altitudes decreases their effectiveness. As the airplane approaches its absolute altitude, the controls become sluggish, making altitude and heading difficult to maintain. For this reason, most airplanes that fly at above 25,000 feet are equipped with an autopilot.

b. A determined weight of air is used by the engine for producing an identified amount of horsepower through internal combustion. For a given decrease of air density, horsepower decreases at a higher rate which is approximately 1.3 times that of the corresponding decrease in air density.

c. For an airplane to maintain level flight, drag and thrust must be equal. Because density is always greatest at sea level, the velocity at altitude given the same angle of attack will be greater than at sea level, although the indicated air speed (IAS) will not change. Therefore, an airplane's TAS increases with altitude while its IAS remains constant. In addition, an airplane's rate of climb will decrease with altitude.

110. EMERGENCIES AND IRREGULARITIES AT HIGH ALTITUDES. All emergency procedures in the AFM should be reviewed before flying any airplane, and be readily accessible during every flight. A description of some of the most significant high-altitude emergencies and remedial action for each follows.

a. Decompression is defined as the inability of the aircraft's pressurization system to maintain its designed pressure schedule. Decompression can be caused by a malfunction of the system itself or by structural damage to the aircraft. A decompression will often result in cabin fog because of the rapid drop in temperature and the change in relative humidity. A decompression will also affect the human body. Air will escape from the lungs through the nose and mouth because of a sudden lower pressure outside of the lungs. Differential air pressure on either side of the eardrum should clear automatically. Exposure to wind blast and extremely cold temperatures are other hazards the human body may face with decompression.

b. Decompression of a small cabin volume pressurized aircraft is more critical than a large one, given the same size hole or conditions, primarily because of the difference in cabin volumes. Table 1-3 is a comparison of cabin volume ratios between several large transport airplanes and some of the more popular general aviation turbojet airplanes in current use. Table 1-3 shows that, under the same conditions, a typical small pressurized aircraft can be expected to decompress on the order of 10 to 200 times faster than large aircraft. The B-747/Learjet comparison is an extreme example in that the human response, TUC, and the protective equipment necessary are the same. Actual decompression times are difficult to calculate due to many variables involved (e.g., the type of failure, differential pressure, cabin volume, etc.). However, it is more probable that the crew of the small aircraft will have less time in which to take lifesaving actions.

TABLE 1-3. AIRCRAFT CABIN VOLUME RATIOS

Aircraft Type	Cabin Volumes in Cubic Feet	Ratio
DC-9 vs CE-650	5,840 vs 576	10:1
B-737 vs LR-55	8,010 vs 502	16:1
B-727 vs NA-265	9,045 vs 430	21:1
L-1011 vs G-1159	35,000 vs 1,850	19:1
B-747 vs Learjet	59,000 vs 265	223:1

Data Source: Physiological Considerations and Limitations in the High-altitude Operation of SmallVolume Pressurized Aircraft. E. B. McFadden and D. de Steigner, Federal Aviation Administration (FAA) Civil Aeromedical Institute (CAMI).

(1) An explosive decompression is a change in cabin pressure faster than the lungs can decompress. Most authorities consider any decompression which occurs in less than 0.5 seconds as explosive and potentially dangerous. This type of decompression is more likely to occur in small volume pressurized aircraft than in large pressurized aircraft and often results in lung damage. To avoid potentially dangerous flying debris in the event of an explosive decompression, all loose items such as baggage and oxygen cylinders should be properly secured.

(2) A rapid decompression is a change in cabin pressure where the lungs can decompress faster than the cabin. The risk of lung damage is significantly reduced in this decompression as compared with an explosive decompression.

(3) Gradual or slow decompression is dangerous because it may not be detected. Automatic visual and aural warning systems generally provide an indication of a slow decompression.

(4) Recovery from all types of decompression is similar. Oxygen masks should be donned, and a rapid descent initiated as soon as possible to avoid the onset of hypoxia. Although top priority in such a situation is reaching a safe altitude, pilots should be aware that cold-shock in piston engines can result from a high-altitude rapid descent, causing cracked cylinders or other engine damage. The time allowed to make a recovery to a safe altitude before loss of useful consciousness is, of course, much less with an explosive decompression than with a gradual decompression.

c. Increased oil temperature, decreased oil pressure, and a drop in manifold pressure could indicate a turbocharger malfunction or a partial or complete turbocharger failure. The consequences of such a malfunction or failure are twofold. The airplane would not be capable of sustaining altitude without the additional power supplied by the turbocharged system. The loss in altitude in itself would not create a significant problem, weather and terrain permitting, but ATC must be notified of the descent. A more serious problem associated with a failed turbocharger would be loss of cabin pressurization if the pressurization system is dependent on the turbocharger compressor. Careful monitoring of pressurization levels is essential during the descent to avoid the onset of hypoxia from a slow decompression.

d. Another potential problem associated with turbochargers is fuel vaporization. Engine-driven pumps that pull fuel into the intake manifold are susceptible to vapor lock at high altitudes. Most high-altitude aircraft are equipped with tank-mounted boost pumps to feed fuel to the engine-driven pump under positive pressure. These pumps should be turned on if fuel starvation occurs as a result of vapor lock.

e. Because of the highly combustible composition of oxygen, an immediate descent to an altitude where oxygen is not required should be initiated if a fire breaks out during a flight at high altitude. The procedures in the AFM should be followed.

f. Flight through thunderstorm activity or known severe turbulence should be avoided, if possible. When flight through severe turbulence is anticipated and/or unavoidable, the following procedures are highly recommended:

(1) Airspeed is critical for any type of turbulent air penetration. Use the AFM recommended turbulence penetration target speed or, if unknown, an airspeed below maneuvering speed. Use of high airspeeds can result in structural damage and injury to passengers and crewmembers. Severe gusts may cause large and rapid variations in indicated airspeed. Do not chase airspeed.

(2) Penetration should be at an altitude that provides adequate maneuvering margins in case severe turbulence is encountered to avoid the potential for catastrophic upset.

(3) If severe turbulence is penetrated with the autopilot on, the altitude hold mode should be off. If the autopilot has an attitude hold mode, it should be engaged. The autopilot attitude hold mode can usually maintain attitude more successfully than a pilot under stress. With the autopilot off, the yaw damper should be engaged. Controllability of the aircraft in turbulence becomes more

difficult with the yaw damper off. Rudder controls should be centered before engaging the yaw damper.

(4) When flight through a thunderstorm cannot be avoided, turn up the intensity of panel and cabin lights so lightening does not cause temporary blindness. White lighting in the cockpit is better than red lighting during thunderstorms.

(5) Keep wings level and maintain the desired pitch attitude and approximate heading. Do not attempt to turn around and fly out of the storm because the speed associated with thunderstorms usually makes such attempts unsuccessful. Use smooth, moderate control movements to resist changes in attitude. If large attitude changes occur, avoid abrupt or large control inputs. Avoid, as much as possible, use of the stabilizer trim in controlling pitch attitudes. Do not chase altitude.

111. FLIGHT TRAINING. Flight training required to comply with 14 CFR section 61.31(f) may be conducted in a high-altitude airplane or a simulator that meets the requirements of 14 CFR section 121.407. The simulator should be representative of an airplane that has a service ceiling or maximum operating altitude, whichever is lower, above 25,000 feet MSL. The training should consist of as many flights as necessary to cover the following procedures and maneuvers. If an airplane is being used, each flight should consist of a preflight briefing, flight planning, a preflight inspection, demonstrations by the instructor of certain maneuvers or procedures when necessary, and a postflight briefing and discussion.

a. Preflight Briefing. The instructor should verbally cover the material that will be introduced during the flight. If more than one flight is required, previous flights should be reviewed at this time. The preflight briefing is a good time to go over any questions the trainee may have regarding operations at high altitudes or about the aircraft. Questions by the trainee should be encouraged during all portions of the flight training.

b. Preflight Planning. A thorough flight plan should be completed for a predetermined route. The flight plan should include a complete weather briefing. If possible, a trip to a Flight Service Station (FSS) is encouraged rather than a telephone briefing so the trainee can use actual weather charts. Winds, pilot reports, the freezing level and other meteorological information obtained from the briefing should be used to determine the best altitude for the flight. The information should be retained for future calculations.

(1) The course should be plotted on high-altitude navigation chart noting the appropriate jet routes and required reporting points on a navigation log. Low-altitude charts should be available for planning departures and arrivals to comply with airspace and airspeed requirements. Alternate airports should also be identified and noted.

(2) The AFM should be reviewed with particular attention to weight and balance, performance charts, and emergency procedures. Oxygen requirements, airspeeds, groundspeeds, time en route, and fuel burn should be calculated using the AFM and weather data, when applicable. Fuel management and descents should also be planned at this time. The AFM should be readily accessible in the cabin in the event of an emergency.

(3) A flight plan should be completed using appropriate jet routes from the en route high-altitude chart. The flight plan should be filed with the nearest Flight Service Station or ATC facility as appropriate.

c. Preflight Inspection. The aircraft checklist should be followed carefully. Particular attention should be given to the aircraft's fuselage, windshields, window panels, and canopies to identify any cracks or damage that could rupture under the stress of cabin pressurization. The inspection should also include a thorough examination of the aircraft oxygen equipment, including available supply, an operational check of the system, and assurance that supplemental oxygen is in a readily accessible location.

(1) Preflighting the oxygen equipment so that the system is ready for use as soon as the mask is donned.

(2) Including a requirement to demonstrate that the crew can establish communications using the oxygen equipment, both between crewmembers, if more than one required pilot, and with ATC.

d. Runup, Takeoff, and Initial Climb. Procedures in the AFM should be followed, particularly the manufacturer's recommended power settings and airspeeds to avoid overboosting the engine. Standard call-out procedures are highly recommended and should be used for each phase of flight where the airplane crew consists of more than one crewmember.

e. Climb to High Altitude and Normal Cruise Operations While Operating Above 25,000 feet MSL. The transition from low to high altitude should be performed repeatedly to assure familiarity with appropriate procedures. Specific oxygen requirements should be met when climbing above 12,500 feet and pressurization should be adjusted with altitude. When passing through FL 180, the altimeter should be set to 29.92" Hg and left untouched until descending below that altitude. Reporting points should be complied with, as should appropriate altitude selection for direction of flight. Throughout the entire climb and cruise above 25,000 feet, emphasis should be given to monitoring cabin pressurization.

f. Simulated Emergencies. Training should include at least one simulated rapid decompression and emergency descent. Do not actually depressurize the airplane for this or any other training. Actual decompression of an airplane can be extremely dangerous and should never be done intentionally for training purposes. The decompression should be simulated by donning the oxygen masks, turning on the oxygen controls, configuring the airplane for an emergency descent, and performing the emergency descent as soon as possible. This maneuver can be practiced at any altitude.

g. Descents. Gradual descents from altitude should be practiced to provide passenger comfort and compliance with procedures for transitioning out of the high-altitude realm of flight. The airplane manufacturer's recommendations should be followed with regard to descent power settings to avoid stress on the engine and excessive cooling. Particular emphasis should be given to cabin pressurization and procedures for equalizing cabin and ambient pressures before landing. Emphasis should also be given to changing to low-altitude charts when transitioning through FL 180, obtaining altimeter settings below FL 180, and complying with airspace and airspeed restrictions at appropriate altitudes.

h. Engine Shutdown. Allow the turbocharged engine to cool for at least one minute and assure that all shutdown procedures in the AFM are followed. Before exiting the airplane, always check that all oxygen equipment and oxygen valves have been turned off or placed in the position recommended by the manufacturer.

i. Postflight Discussion. The instructor should review the flight and answer any questions the trainee may have. If additional flights are necessary to ensure thorough understanding of high-altitude operations, the material for the next flight should be previewed during the postflight discussion.

112. - 199. RESERVED.

CHAPTER 2. MACH FLIGHT AT HIGH ALTITUDES

200. PURPOSE. To present certain factors involved in the high-speed flight environment at high altitudes. It is the lack of understanding of many of these factors involving the laws of aerodynamics, performance, and MACH speeds that has produced a somewhat higher accident rate in some types of turbojet aircraft

201. CRITICAL ASPECTS OF MACH FLIGHT. In recent years, a number of corporate jet airplanes have been involved in catastrophic loss of control during high-altitude/high-speed flight. A significant causal factor in these accidents may well have been a lack of knowledge by the pilot regarding critical aspects of high-altitude, MACH flight.

a. Maximum operating altitudes of general aviation turbojet airplanes now reach 51,000 feet. It is, therefore, logical to expect these types of accidents to continue unless pilots learn to respect the more critical aspects of high-altitude, high-speed flight and gain as much knowledge as possible about the specific make and model of aircraft to be flown and its unique limitations.

b. From the pilot's viewpoint, MACH is the ratio of the aircraft's true airspeed to the local speed of sound. At sea level, on a standard day (59° F/15° C) the speed of sound equals approximately 660 Kts or 1,120 feet per second. MACH 0.75 at sea level is equivalent to a TAS of approximately 498 Kts (0.75 x 660 Kts) or 840 feet per second. The temperature of the atmosphere normally decreases with an increase in altitude. The speed of sound is directly related only to temperature. The result is a decrease in the speed of sound up to about 36,000 feet.

c. The sleek design of some turbojet airplanes has caused some operators to ignore critical airspeed and MACH limitations. There are known cases in which corporate turbojet airplanes have been modified by disabling the airspeed and MACH warning systems to permit intentional excursions beyond the FAA certificated V_{MO}/M_{MO} limit for the specific airplane. Such action may critically jeopardize the safety of the airplane by setting the stage for potentially hazardous occurrences.

d. The compulsion to go faster may result in the onset of aerodynamic flutter, which in itself can be disastrous, excessive G-loading in maneuvering, and induced flow separation over the ailerons and elevators. This may be closely followed by the physical loss of a control surface, an aileron buzz or snatch, coupled with yet another dangerous phenomenon called MACH tuck, leading to catastrophic loss of the airplane and the persons onboard.

e. MACH-tuck is caused principally by two basic factors:

(1) Shock wave-induced flow separation, which normally begins near the wing root, causes a decrease in the down wash velocity over the elevator and produces a tendency for the aircraft to nose down.

(2) Aftward movement of the center of pressure, which tends to unbalance the equilibrium of the aircraft in relation to its center of gravity (CG) in subsonic flight.

f. The airplane's CG is now farther ahead of the aircraft's aerodynamic center than it was in slower flight. This dramatically increases the tendency of the airplane to pitch more nose down.

g. Pressure disturbances in the air caused by an airfoil in high-altitude/high-speed flight result from molecular collisions. These molecular collisions are the result of air that moves over an airfoil faster than the air it is overtaking can dissipate. When the disturbance reaches a point at which its propagation achieves the local speed of sound, MACH 1 is attained. One hundred percent (100%) of the speed of sound at MSL with a temperature of 15° C is 760 statute or 660 NM per hour. This speed is affected by temperature of the atmosphere at altitude. Thus, optimum thrust fuel, and range considerations are significant factors in the design of most general aviation turbine powered airplanes which cruise at some percentage of MACH 1.

h. Because of the critical aspects of high-altitude/high-MACH flight, most turbojet airplanes capable of operating in the MACH speed ranges are designed with some form of trim and autopilot MACH compensating device (stick puller) to alert the pilot to inadvertent excursions beyond its certificated M_{MO}. This stick puller should never be disabled during normal flight operations in the aircraft.

i. If for any reason there is a malfunction that requires disabling the stick puller, the aircraft must be operated at speeds well below M_{MO} as prescribed in the applicable AFM procedures for the aircraft.

j. An airplane's IAS decreases in relation to TAS as altitude increases. As the IAS decreases with altitude, it progressively merges with the low-speed buffet boundary where prestall buffet occurs for the airplane at a load factor of 1.0 G. The point where high-speed MACH, IAS, and low-speed buffet boundary IAS merge is the airplane's absolute or aerodynamic ceiling. Once an aircraft has reached its aerodynamic ceiling, which is higher than the altitude limit stipulated in the AFM, the aircraft can neither be made to go faster without activating the design stick puller at MACH limit nor can it be made to go slower without activating the stick shaker or pusher. This critical area of the aircraft's flight envelope is known as coffin corner.

k. MACH buffet occurs as a result of supersonic airflow on the wing. Stall buffet occurs at angles of attack that produce airflow disturbances (burbling) over the upper surface of the wing which decreases lift. As density altitude increases, the angle of attack that is required to produce an airflow disturbance over the top of the wing is reduced until a density altitude is reached where MACH buffet and stall buffet converge (described in paragraph 5n as coffin corner). When this phenomenon is encountered, serious consequences may result causing loss of control of the aircraft.

l. Increasing either gross weight or load factor (G factor) will increase the low-speed buffet and decrease MACH buffet speeds. A typical turbojet airplane flying at 51,000 feet altitude at 1.0 G may encounter MACH buffet slightly above the airplane's M_{MO} (0.82 MACH) and low speed buffet at 0.60 MACH. However, only 1.4 G (an increase of only 0.4 G) may bring on buffet at the optimum speed of 0.73 MACH and any change in airspeed, bank angle, or gust loading may reduce this straight and level flight 1.4 G protection to no protection. Consequently, a maximum cruising flight altitude must be selected which will allow sufficient buffet margin for the maneuvering necessary and for gust conditions likely to be encountered. Therefore, it is important for pilots to be familiar with the use of charts showing cruise maneuvering and buffet limits. Flightcrews operating airplanes at high speeds must be adequately trained to operate them safely. This training cannot be complete until pilots are thoroughly educated in the critical aspect of aerodynamic factors described herein pertinent to MACH flight at high altitudes.

202. AIRCRAFT AERODYNAMICS AND PERFORMANCE. Pilots who operate aircraft at high speeds and high altitudes are concerned with the forces affecting aircraft performance caused by the interaction of air on the aircraft. With an understanding of these forces, the pilot will have a sound basis for predicting how the aircraft will respond to control inputs. The importance of these aerodynamic forces and their direct application to performance and execution of aircraft maneuvers and procedures at altitude will be evident. The basic aerodynamics definitions that apply to high-altitude flight are contained in paragraph 3, Definitions.

a. Wing Design.

(1) The wing of an airplane is an airfoil or aircraft surface designed to obtain the desired reaction from the air through which it moves. The profile of an aircraft wing is an excellent example of an efficient airfoil. The difference in curvature between the upper and lower surfaces of the wing generates a lifting force. Air passing over the upper wing surface moves at a higher velocity than the air passing beneath the wing because of the greater distance it must travel over the upper surface. This increased velocity results in a decrease in pressure on the upper surface. The pressure differential created between the upper and lower surfaces of the wing lifts the wing upward in the direction of the lowered pressure. This lifting force is known as induced lift. Induced lift may be increased, within limits, by:

(a) Increasing the angle of attack of the wing or changing the shape of the airfoil, changing the geometry, e.g., aspect ratio.

(b) Increasing the wing area.

(c) Increasing the free-stream velocity.

(d) A change in air density.

(2) The pilot may have only varying degrees of control over these factors. Thus, the pilot must keep firmly in mind that an aircraft will obey the laws of physics just as precisely at its high-speed limits as it does during a slower routine flight, and that regardless of wing shape or design, MACH range flight requires precise control of a high volume of potential energy without exceeding the critical MACH number or MACH crit.

(3) MACH crit is important to high-speed aerodynamics because it is the speed at which the flow of air over a specific airfoil design reaches MACH 1, but the most important effect is formation of a shock wave and drag divergence.

(4) Sweeping the wings of an airplane is one method used by aircraft designers to delay the adverse effects of high MACH flight and bring about economical cruise with an increase in the critical MACH number. Sweep allows a faster airfoil speed before critical MACH is reached when compared to an equal straight wing. This occurs because the airflow now travels over a different cross section (camber) of the airfoil. This new cross section has less effective camber which results in a reduced acceleration of airflow over the wing, thus allowing a higher speed before critical MACH is reached. Sweep may be designed either forward or rearward; the overall effect is the same. However, rearward sweep appears to be somewhat more desirable, since it has rapidly presented fewer problems to manufacturers of models of general aviation aircraft in terms of

unwanted design side effects. In effect, the wing is flying slower than the airspeed indicator indicates and, similarly, it is developing less drag than the airspeed indicator would suggest. Since less drag is being developed for a given indicated airspeed, less thrust is required to sustain the aircraft at cruise flight.

(5) There is a penalty, however, on the low-speed end of the spectrum. Sweeping the wings of an aircraft increases the landing/stall speed which, in turn, means higher touchdown speed, with proportionally longer runway requirements and more tire and brake wear as opposed to a straight-wing design. A well-stabilized approach with precise control of critical "V" speeds is necessary. In other words, to achieve a safe margin airspeed on the wing that will not result in a stalled condition with the wingtips stalling prior to the rest of the wing and possibly rolling uncontrollably to the right or left, the swept-wing aircraft must be flown at a higher actual airspeed than a straight wing aircraft.

(6) Drag curves are approximately the reverse of the lift curves, in that a rapid increase in drag component may be expected with an increase of angle of attack with the swept wing; the amount being directly related to the degree of sweep or reduction of aspect ratio.

(7) The extension of trailing edge flaps and leading edge devices may, in effect, further reduce the aspect ratio of the swept wing by increasing the wing chord. This interplay of forces should be well understood by the pilot of the swept-wing aircraft, since raising the nose of the aircraft to compensate for a mild undershoot during a landing approach at normal approach speeds will produce little lift, but may instead lead to a rapid decay in airspeed, thus critically compromising the margin of safety

(8) Another method of increasing the critical MACH number of an aircraft wing is through the use of a high-speed laminar airflow airfoil in which a small leading edge radius is combined with a reduced thickness ratio. This type of wing design is more tapered with its maximum thickness further aft, thus distributing pressures and boundary layer air more evenly along the chord of the wing. This tends to reduce the local flow velocities at high MACH numbers and improve aircraft control qualities.

(9) Several modern straight-wing, turbojet aircraft make use of the design method described in subparagraph (4). To delay the onset of MACH buzz and obtain a higher M_{MO}, these aircraft designs may incorporate the use of both vortex generators and small triangular upper wing strips as boundary layer energizers. Both systems seem to work equally well, although the boundary layer energizers generally produce less drag. Vortex generators are small vanes affixed to the upper wing surface, extending approximately 1 to 2 inches in height. This arrangement permits these vanes to protrude through the boundary layer air. The vortex generators deflect the higher energy airstream downward over the trailing edge of the wing and accelerate the boundary layer aft of the shock wave. This tends to delay shock-induced flow separation of the boundary layer air which causes aileron buzz, and thus permits a higher M_{MO}. The lift characteristics of straight-wing and swept-wing airplanes related to changes in angle of attack are more favorable for swept-wing airplanes. An increase in the angle of attack of the straight-wing airplane produces a substantial and constantly increasing lift vector up to its maximum coefficient of lift and, soon thereafter, flow separation (stall) occurs with a rapid deterioration of lift.

(10) By contrast, the swept wing produces a much more gradual buildup of lift with no well-defined maximum coefficient, the ability to fly well beyond this point, and no pronounced stall break. The lift curve of the short, low-aspect ratio (short span, long chord) wing used on present-day military fighter aircraft compares favorably with that of the swept wing, and that of other wing designs which may be even more shallow and gentle in profile.

(11) Regardless of the method used to increase the critical MACH number, airflow over the wing is normally smooth. However, as airspeed increases, the smooth flow becomes disturbed. The speed at which this disturbance is usually encountered is determined by the shape of the wing and the degree of sweep.

(12) When the aircraft accelerates, the airflow over the surface of the wing also accelerates until, at some point on the wing, it becomes sonic. The indicated airspeed at which this occurs is the critical MACH number (MACH crit) for that wing.

b. Jet Engine Efficiency.

(1) The efficiency of the jet engine at high altitudes is the primary reason for operating in the high-altitude environment. The specific fuel consumption of jet engines decreases as the outside air temperature decreases for constant revolutions per minute (RPM) and TAS. Thus, by flying at a high altitude, the pilot is able to operate at flight levels where fuel economy is best and with the most advantageous cruise speed. For efficiency, jet aircraft are typically operated at high altitudes where cruise is usually very close to RPM or exhaust gas temperature limits. At high altitudes, little excess thrust may be available for maneuvering. Therefore, it is often impossible for the jet aircraft to climb and turn simultaneously, and all maneuvering must be accomplished within the limits of available thrust and without sacrificing stability and controllability.

(2) Compressibility also is a significant factor in high-altitude flight. The low temperatures that make jet engines more efficient at high altitudes also decrease the speed of sound. Thus, for a given TAS, the MACH number will be significantly higher at high altitude than at sea level. This compressibility effect due to supersonic airflow will be encountered at slower speeds at high altitude than at low altitude.

c. Controllability Factors.

(1) Static stability is the inherent flight characteristic of an aircraft to return to equilibrium after being disturbed by an unbalanced force or movement.

(2) Controllability is the ability of an aircraft to respond positively to control surface displacement, and to achieve the desired condition of flight.

(3) At high-flight altitudes, aircraft stability and control may be greatly reduced. Thus, while high-altitude flight may result in high TAS and high MACH numbers, calibrated airspeed is much slower because of reduced air density. This reduction in density means that the angle of attack must be increased to maintain the same coefficient of lift with increased altitude. Consequently, jet aircraft operating at high altitudes and high MACH numbers may simultaneously experience problems associated with slow-speed flight such as Dutch roll, adverse yaw, and stall. In

addition, the reduced air density reduces aerodynamic damping, overall stability, and control of the aircraft in flight.

(a) Dutch roll is a coupled oscillation in roll and yaw that becomes objectionable when roll, or lateral stability is reduced in comparison with yaw or directional stability. A stability augmentation system is required to be installed on the aircraft to dampen the Dutch roll tendency when it is determined to be objectionable, or when it adversely affects control stability requirements for certification. The yaw damper is a gyro-operated autocontrol system installed to provide rudder input and aid in canceling out yaw tendencies such as those in Dutch roll.

(b) Adverse yaw is a phenomenon in which the airplane heading changes in a direction opposite to that commanded by a roll control input. It is the result of unequal lift and drag characteristics of the down-going and up-going wings. The phenomena are alleviated by tailoring the control design by use of spoilers, yaw dampers, and interconnected rudder and aileron systems.

(4) Supersonic flow over the wing is responsible for:

(a) The formation of shock waves on the wing which result in drag rise.

(b) An aft shift in the center of lift resulting in a nosedown pitching moment called MACH tuck.

(c) Airflow separation behind the shock waves resulting in MACH buffet.

(5) Swept wing and airfoil design alone, with boundary layer energizers such as the vortex generators described earlier, has reduced the hazardous effect of the problems described above. However, these problems are still encountered to some extent by the modern turbojet airplane in high-altitude flight.

(6) In general, this discussion has been confined to normal level, unaccelerated 1.0 G-flight, when turning or maneuvering about the pitch axis; however, acceleration of G-forces can occur while maintaining a constant airspeed. As G-forces increase, both the aircraft's aerodynamic weight and angle of attack increase. The margin over low-speed stall buffet decreases, as well as the margin below MACH buffet, because of the increased velocity of the air over the wing resulting from the higher angle of attack. This, in effect, could lower the aerodynamic ceiling for a given gross-weight. Increased G-loading can also occur in non-maneuvering flight because of atmospheric turbulence or the lack of fine-touch skill by the pilot. Pilots flying at high altitudes in areas where turbulence may be expected must carefully consider acceptable safety margins necessary to accommodate the sudden and unexpected vertical accelerations which may be encountered with little or no warning. How wide is the safety margin between low-speed and high-speed buffet boundaries for an altitude and weight in a 30° bank? The answer may be easily determined by reference to the Cruise Maneuver/Buffet Limit Chart for a particular aircraft. For example, in a typical jet aircraft, the 1.0 G buffet-free margin at FL 350 is 135 Kts; at FL 450 this speed is reduced to a mere 26 Kts. Thus, the safety margin in airspeed spread diminishes rapidly as the aircraft climbs and leaves little room for safety in the event of an air turbulence encounter or accidental thunderstorm penetration.

(7) If a thunderstorm cannot be avoided, follow high-altitude thunderstorm penetration procedures and avoid over-action of thrust levers. When excessive airspeed buildup occurs, pilots may wish to use speed brakes. The use of aerodynamic speed brakes, when they are part of the lateral control system, may change the roll rate any time there is a lateral control input.

(8) For detailed information concerning the operation of specific turbojet aircraft, refer to the aircraft's AFM.

203. - 299. RESERVED.