The Pilot's Manual

Airline Transport Pilot

All the aeronautical knowledge required for the ATP Certification Training Program

Mark Dusenbury
Shayne Daku







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The Pilot's Manual: Airline Transport Pilot
by Mark Dusenbury and Shayne Daku

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Introduction

ATP CTP History

On February 12, 2009, a Colgan Air Bombardier Dash-8 Q400 operating as Continental Connection 3407 experienced a loss of control on an instrument approach into Buffalo Niagara International Airport in Buffalo, New York, and crashed 5 nautical miles northeast of the airport, killing all 49 passengers on board and one person on the ground. Exactly one year following the accident, the National Transportation Safety Board (NTSB) Aircraft Accident Report listed the probable cause of the accident as, "… the captain's inappropriate response to the activation of the stick shaker, which led to an aerodynamic stall from which the airplane did not recover." The report further listed four contributing factors to the accident: "(1) the flight crew's failure to monitor airspeed in relation to the rising position of the low-speed cue, (2) the flight crew's failure to adhere to sterile cockpit procedures, (3) the captain's failure to effectively manage the flight, and (4) Colgan Air's inadequate procedures for airspeed selection and management during approaches in icing conditions." Furthermore, the final accident report listed 46 findings, many of which resulted in major changes to the certification and training of airline pilots.

The families of the victims of Colgan Air 3407 lobbied Congress heavily for numerous safety improvements relating directly to the findings of the NTSB accident investigation. On August 1, 2010, President Barack Obama signed Public Law 111-216, the Airline Safety and Federal Aviation Administration Extension Act of 2010, which was effective August 2, 2013. This Public Law had massive repercussions for the FAA and the airlines. In fact, much of the content of this book is centered around concepts outlined in this Public Law and the FAA's response to it.

Below is a list of the sections that apply directly to the certification and operation of pilots under 14 CFR Part 121:

- Section 206: Requires the FAA Administrator to convene an Aviation Rulemaking Committee to make recommendations focused on the areas of mentoring, professional development, and leadership, and then conduct a rulemaking based on these findings.
- Section 207: Requires the FAA Administrator to conduct a study of industry best practices with regard to pilot pairing, crew resource management techniques, and pilot commuting. The Administrator shall then submit to Congress's Transportation & Infrastructure Committee and Commerce Committee a report on the findings of this study.
- Section 208: Requires the FAA Administrator to conduct rulemakings that require all Part 121 air carriers to provide stall and upset recognition and recovery training as well as to implement remedial training programs. It also forms a multidisciplinary panel to report on stick pusher and weather event training.

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- Section 209: Gives the FAA a timeline to complete its current rulemaking on crewmember training, and forms a multidisciplinary panel to examine a number of issues related to various aspects of pilot training—ground school, recurrent training, assessing proficiency, etc.—and then report to Congress.
- Section 210: Requires all ticket agents, air carriers, and any other persons selling plane tickets to disclose verbally or in writing the name of the carrier actually operating each segment of a flight, and requires internet ticket sites to disclose this information in the initial display after a search.
- Section 211: Requires the FAA Administrator to conduct on-site, random inspections at a minimum of a yearly basis at all regional airlines.
- Section 212: Requires the FAA Administrator to conduct rulemaking establishing new flight and duty time regulations, requires all Part 121 carriers to submit a Fatigue Risk Management Plan for Administrator approval, and directs a study on commuting, with findings to be incorporated into fatigue rulemaking.
- Section 213: Requires the FAA Administrator to report to Congress's Transportation & Infrastructure Committee and Commerce Committee on a carrier-by-carrier basis, detailing which carriers are utilizing Flight Operational Quality Assurance (FOQA), Line Operations Safety Assessments (LOSA), Aviation Safety Action Program (ASAP), and Advanced Qualification Program (AQP), and also examine how the data derived from such programs is being shared across the industry to ensure maximum safety benefit.
- Section 214: Requires the FAA Administrator to develop a plan to facilitate the implementation of ASAP and FOQA at all Part 121 carriers.
- Section 215: Requires the FAA Administrator to conduct a rulemaking to require all Part 121 carriers to implement Safety Management Systems.
- Section 216: Requires the FAA Administrator to conduct a rulemaking that changes screening and qualification requirements for all Part 121 pilots, requiring an ATP license and appropriate multi-engine experience. It includes a default provision that the ATP requirement is mandatory within 3 years.
- Section 217: Requires the FAA Administrator to conduct a rulemaking that modifies the requirements to earn an Airline Transport Pilot (ATP) license. It focuses on flight hours (including in difficult operational conditions) and additional qualitative elements.

The FAA convened several Aviation Rulemaking Committees (ARC) to respond to the mandates made by Public Law 111-216. An ARC is a group of FAA employees and industry experts and stakeholders tasked with the creation or revision of aviation regulations. The final ruling from the First Officer Qualification (FOQ) ARC was issued July 10, 2013. The final rule had six primary provisions, or changes, to the regulation:

1. All pilots operating under Part 121 operations are required to hold an Airline Pilot Transport (ATP) certificate beginning August 1, 2013.
2. All pilots seeking an ATP certificate with a multi-engine class rating are required to complete an Airline Transport Pilot Certificate Training Program (ATP-CTP) prior to taking the ATP knowledge test.
3. All second-in-command (SIC) pilots in Part 121 operations must have a type rating for the aircraft being flown.
4. A minimum of 50 hours of multi-engine flight time is required in order to qualify for an ATP certificate.

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5. A Restricted Airline Transport Pilot (R-ATP) certificate was established, enabling pilots who meet certain prescribed criteria to operate as an SIC in Part 121 operations.
6. A minimum of 1,000 hours of flight experience in air carrier operations is required prior to serving as a pilot-in-command (PIC) in Part 121 operations.

Many of the requirements of the FOQ ARC are explained in detail throughout this book. It's important to note that this book does not focus solely upon the regulatory changes resulting from Public Law 111-216. Instead, the intent of this book is to prepare an airline pilot candidate in all areas relating to their desired occupation. Being an airline pilot demands a well-rounded candidate—someone who is skilled in the operation and handling of aircraft and who is of utmost professional and moral character. This book covers many of the technical areas while highlighting what it means to be an aviation professional.

Topics Covered in This Book

This manual covers a wide variety of topics relating to airline operations. The format and order of its content is centered on Advisory Circular (AC) 61-138, which was created by the FAA to outline the content required by the Airline Transport Pilot Certification Training Program (ATP-CTP). The ATP-CTP is ground, full flight simulator, and flight training device training that must be completed by an ATP applicant prior to taking the ATP written exam. Written in response to this AC, this book seeks to add to the topics defined by the AC with practical advice on topics pertinent to a newly hired airline pilot.

Section I begins with a review of aerodynamics with a focus on high altitude operations, stall prevention and recovery, and general upset recovery techniques for transport category aircraft. Section II covers pertinent weather considerations, with emphasis on abnormal weather conditions, icing, and severe weather avoidance. Section III deals with general operating considerations when working for an airline, including physiological considerations, checklist procedures, operational control, handling equipment failures, operating turbine engines, transport category performance, and automation. Section IV covers the extremely pertinent and related topics of leadership and professionalism, crew resource management, and safety culture; these provide a basis for what it means to be a professional in the field of aviation. The final section concludes with a discussion of pertinent regulations, including sleep and duty regulations as well as operating rules that differ from general aviation regulations.

This manual is best used in conjunction with *The Pilot's Manual: Airline Transport Pilot Certification Training Program Syllabus* (ASA-PM-S-ATP2PD) and the ASA Test Prep book (ASA-TP-ATP) or Prepware software (ASA-TW-ATP) for Airline Transport Pilot. AC 61-138 also lists several available resources that can be utilized in the course of training, such as aviation accident and investigation reports, advisory circulars, and training aids. These free resources can be found on the Reader Resources webpage for this book (*see* next page).

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Reader Resources

Several chapters throughout this book include a list of additional resources we refer to as reader resources. These resources can be used to expand on the topics covered within the specified chapter. These resources include advisory circulars, NTSB Accident Reports and animations, FAA safety information, training aids, and additional pertinent information which will help the applicant further bridge the knowledge gap to an Airline Transport Pilot Certificate. You can refer to *The Pilot's Manual: Airline Transport Pilot* Reader Resources page at **www.asa2fly.com/reader/pmatp** for direct links to each reader resource outlined within this book.

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Section I

Aerodynamics

1. **High Altitude Operations**
2. **Stall Prevention and Recovery**
3. **Upset Recovery Procedures**

Key Terms:

(in the order they appear in this section)

- potential energy (PE)
- kinetic energy (KE)
- air density
- true airspeed
- pressure wave (shock wave)
- Mach
- V_{MO}
- M_{MO}
- L/D_{MAX}
- aerodynamic ceiling
- wing sweep
- Dutch roll
- transport category aircraft
- angle of attack (AOA)
- pitch angle
- critical angle of attack
- G-loading
- weight
- center of gravity
- tail stall
- wake turbulence

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High Altitude Operations 1

In this chapter:

Principles of Energy Management 3
Measuring Energy 4
Air Density 4
Air Compressibility 5
Mach 5
Energy Limits 5
Managing Energy 7
Recovering Energy at High Altitude 8
Banking in Transport Category Aircraft 8
L/D_{MAX} 10
Atmospheric Considerations 11
Aerodynamic Ceiling 11
Wing Sweep 13
Dutch Roll 13

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Principles of Energy Management

The law of conservation of energy states that energy cannot be created or destroyed but is conserved (remains constant). Energy can be broken into two components: potential energy (PE) and kinetic energy (KE). *Potential energy* is energy that is stored in a static state (e.g., an aircraft at an altitude of 41,000 feet has potential energy as a result of its altitude). *Kinetic energy* is the energy inherent in the mass and velocity of an object (e.g., a 235,000-pound aircraft traveling at 425 knots has kinetic energy because of its mass and speed). The sum of PE and KE equals total energy (TE). PE + KE = TE. In mathematic terms, PE plus KE always equals TE. Therefore, PE and KE have an inverse relationship with one another; as PE increases, KE must decrease in order for TE to remain constant.

Total Energy (TE) is the sum of potential energy and kinetic energy.

What does this mean when applied towards our 235,000-pound aircraft traveling at 425 knots at 41,000 feet? Recall that potential energy is energy stored, such as the altitude of the aircraft in this example. If the aircraft descended (without any change in aircraft power or configuration) the potential energy would be converted into kinetic energy (the airspeed of the aircraft would increase) and total energy remains the same. Conversely, if the aircraft starts to climb, the potential energy will increase and therefore kinetic energy (airspeed) will decrease, assuming that the aircraft power and configuration remains the same. It is important for pilots to have a basic understanding of this law, especially when operating in the higher altitudes where the aircraft is near its limitations.

Measuring Energy

Let's dig a little deeper into how kinetic and potential energy are measured and presented to the pilot. The airspeed indicator measures dynamic air pressure (kinetic energy) while the altimeter measures static air pressure (potential energy). There are errors associated with each of these measurements that need to be understood. The airspeed indicator suffers from errors relating to both air density and air compressibility. We'll look at these errors individually and then discuss the overall impact and considerations when flying an aircraft at high altitude and high airspeed.

Air Density

Air density is the mass (measured as a weight per volume) of the atmosphere. Air density changes as altitude and temperature change. An increase in altitude will result in a decrease in air density, and vice versa. Temperature has the same impact on air density—a higher temperature results in lower air density. Finally, humidity also impacts air density in the same direct fashion (an increase in humidity results in a lower air density). Air density is important from an aerodynamic standpoint as well as an air measurement standpoint. A lower air density reduces the amount of lift produced by a wing, when all other factors are held constant. The airspeed indicator is built to correct for pressure-related air density changes to a certain point. If we consider an extreme case, very high altitudes have an air density near zero. If the air density is zero, the airspeed indicator would not have any ram air force (dynamic air pressure) to measure airspeed with. In short, the effectiveness of the airspeed indicator relates to the density of the air. This is where the concept of true airspeed comes into play. *True airspeed* (TAS) is the speed of the aircraft relative to the air mass in which it is traveling (e.g., how quickly the aircraft is approaching a cloud up ahead). As the air density decreases, the TAS will increase if all other factors remain constant.

Comparing two aircraft both traveling at 250 knots true airspeed, one at 10,000 feet and the other at 20,000 feet, the aircraft at 20,000 feet will show a much lower indicated airspeed. The actual speed that the aircraft are traveling (in relation to the air mass around them) is the same, but the air pressure of the higher aircraft is much lower (14.12 inHg compared with 21.09 inHg). The airspeed indicator uses air pressure in order to discern airspeed; therefore, if the air pressure changes (either dynamic or static) the airspeed indicator will change.

Indicated airspeed is the speed an aircraft is moving through the air as is shown on the airspeed indicator, before any corrections for errors or nonstandard conditions are made.

Described in layman's terms, dynamic air pressure (the stuff measured by an airspeed indicator) is similar to the force that we would feel if we stuck our hand outside of a moving aircraft. This dynamic pressure will decrease if the air density decreases. For example, if you stick your hand out of an aircraft traveling at exactly 200 knots at sea level (where true airspeed and indicated airspeed are the same), and then climbed the aircraft up to 35,000 feet and maintained 200 knots true airspeed (the same speed relative to the air molecules near the aircraft), you would feel less air pressure against your hand. This decrease in air density would result in less dynamic force (given the same speed relative to the air mass) and therefore less indicated airspeed.

As altitude is increased, the true airspeed at which the aircraft will stall increases.

How does this relate to stall speed? Generally, the indicated stall speed does not change much with altitude if all other factors (weight, load factor, configuration, etc.) are held constant. However, the TAS that the aircraft stalls at will increase as altitude increases.

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Air Compressibility

Compressibility is another factor that has an impact both on aerodynamic factors relating to flight as well as on the measurement of airspeed. The concept of compressibility is that air density and pressure will increase directly ahead of an object moving through the air. The faster the object travels through the air, the higher the air density and pressure of the air impacted by the moving object. If an aircraft flies fast enough, it will create a wave of air that builds up in front of it; this is known as a *pressure wave* or *shock wave* (figure 1-1). Shock waves create a lot of problems—such as excessive drag and control problems—for most transport category aircraft. An additional concern occurs when an aircraft travels so fast that airflow surrounding it reaches the speed of sound. Generally, compressibility factors are not a consideration until the aircraft is at high altitude and high airspeed—more than 10,000 feet and 200 knots.

A pressure wave forms in the air as an object, such as an airplane, passes through the air at a speed greater than the speed at which sound can travel.

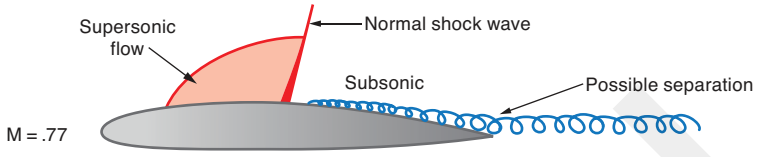


Figure 1-1. Compressibility.

Mach

Mach is a measurement of the speed of the aircraft in relation to the speed of sound. Mach is typically shown as a decimal, with 1.0 Mach (M) equal to the speed of sound; therefore, an aircraft flying at 1.0 Mach is traveling at the speed of sound. The speed of sound varies with air temperature, and temperature in turn varies with altitude. As the altitude increases, the temperature and the speed of sound decreases. Most transport category aircraft will present a Mach readout to the flight crew somewhere on the primary flight display (PFD).

For aircraft that operate in the higher altitudes (above 18,000 feet), the pilots will reference different sources of information in order to determine their kinetic energy limitations. Most transport category aircraft will provide the flight crew with a true airspeed (TAS) reading as well as a Mach reading in addition to the indicated airspeed (IAS) readings.

Energy Limits

There are two limitations relating to airspeed—an upper limit and a lower limit. The lower limit is always the aerodynamic stall speed of the aircraft. This speed varies with aircraft configuration, altitude, load factor, and density altitude. The actual stall speed is not usually shown on the airspeed indicator of a transport category aircraft; instead, the "low speed cue" (figure 1-2), which is higher than the stall speed, is shown. The low speed cue gives the flight crew time to recognize and recover prior to reaching an aerodynamic stall. To give the crew an added warning, transport category aircraft incorporate a "stick shaker," which shakes the control column to simulate an aerodynamic buffet. This stick shaker will activate at the low speed cue. If the crew continues to slow the aircraft down to just above the aerodynamic stall, the stick shaker will turn into a "stick pusher," which will push the flight controls forward

Stick shaker is an artificial stall warning device that vibrates the control column.

Stick pusher is a device that applies an abrupt and large forward force on the control column when the airplane is nearing an angle of attack at which a stall could occur.

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in an attempt to prevent a full aerodynamic stall. The flight crew can override this feature by holding a stick pusher override button on the control column. There are very few reasons why a flight crew would need to use the stick pusher override button, primarily during a wind shear recovery when maximum aerodynamic performance is needed, or in a case in which the airspeed reading falls to 0 either due to a pitot tube blockage or an air data computer (ADC) failure. It could also be possible for the stick pusher system to inadvertently activate due to an internal error, but these cases are very rare. In almost every situation, when the stick pusher activates, the crew should execute a stall recovery. Most airlines provide crews with a recommended minimum flight speed, which varies based on aircraft weight, configuration, and altitude. This minimum flight speed gives the crew adequate protection from the lower speed limit. Stall prevention and recovery will be discussed in greater detail in the next chapter.

V_{MO}/M_{MO} = maximum operating limit speed.

In the upper speed range, there are two limitations that the crew needs to be aware of: V_{MO} and M_{MO}. Each of these limits is a result of different conditions, so they will be discussed separately. V_{MO} is a structural limitation resulting from the dynamic forces placed on the aircraft at excessive speeds. This speed is expressed in knots indicated airspeed. The V_{MO} limitation typically changes with altitude and is represented on the airspeed indicator as a red and black bar similar to the low speed cue (figure 1-2). The V_{MO} limitation is typically set to protect the windows from excessive force or catastrophic failure from bird strikes. As the aircraft climbs in altitude, the V_{MO} limitation becomes less of a factor (because of the decrease in air density and volume of birds) and M_{MO} becomes a more restrictive limitation. M_{MO} (also referred to as limiting Mach) is an aerodynamic limitation to prevent the aircraft from experiencing shockwave-related control problems. If a flight crew were to exceed M_{MO}, they would likely experience control problems resulting from some compressibility-induced shockwave forming on a part of the aircraft. These control issues can be aileron buzz (where the ailerons start to vibrate excessively), Mach tuck (where the nose of the aircraft starts to pitch downward), or physical damage to the wing or tail structures due to wing twist. M_{MO} is also shown on the airspeed indicator by a red and black bar; in fact, both V_{MO} and M_{MO} are displayed in the same fashion without the crew being aware of which limitation is being represented. The air data computer (ADC) will always provide the pilots with the most restrictive of the two limitations so either way, the crew should avoid exceeding the upper limit (known by most pilots as the "barber pole") (figure 1-3).

Whenever a limiting speed is expressed in terms of Mach number, it is expressed as an "M speed." For example, V_{MO} Maximum operating limit speed (in knots), M_{MO} Maximum operating limit speed (in Mach).



Figure 1-2. Low speed cue.



Figure 1-3. Barber Pole.

Managing Energy

Once the flight crew is aware of the varying measurements in airspeed and the associated deficiencies, they will need to manage each of these to ensure safe and efficient margins are maintained. Aircraft climb performance is based on the excess power available (see figure 1-4). The difference between thrust required and thrust available is called excess thrust. An aircraft's climb performance is directly related to the amount of excess thrust available: the more excess thrust available, the higher the climb performance capability, and vice versa. Thrust required varies with aircraft weight, configuration, and altitude, while thrust available changes with altitude (both pressure and density). As weight decreases, the minimum thrust required to maintain flight decreases, resulting in more excess thrust available and more climb performance. Conversely, as the aircraft weight increases, the minimum thrust required increases and excess thrust decreases. Thrust available also decreases as the aircraft climbs in altitude and the air density decreases. Therefore, as an aircraft climbs in altitude, the excess thrust will decrease until finally, thrust required and thrust available are equal. This will result in the aircraft no longer being able to climb. The only way for the aircraft to attain a higher altitude is for it to decrease in weight (by burning fuel).

Most transport category aircraft cannot take off at maximum gross takeoff weight and climb all the way up to their maximum operating altitude. In many cases, the crew will have to conduct what is known as a step climb. They will climb the aircraft to an intermediate altitude and burn fuel until the aircraft is light enough to climb to a higher altitude. Flight crews are provided with climb performance charts, which indicate the maximum attainable altitude for a given aircraft weight and outside air temperature.

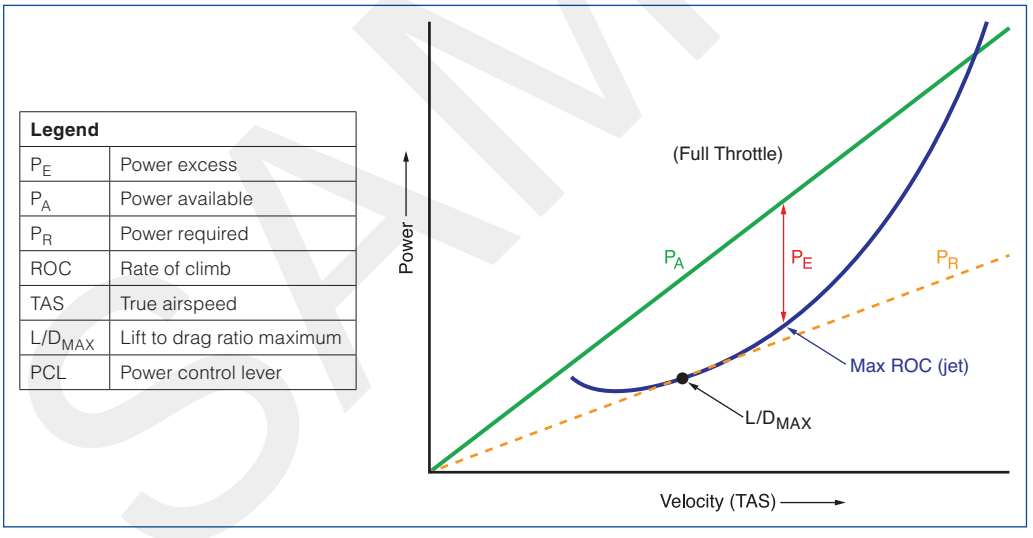


Figure 1-4. Power chart.

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To illustrate this, let's look at an example: A CRJ 200 flying from KPHL to KMSP and weighing 52,000 pounds at takeoff. In order to attain an altitude of FL370, the aircraft weight must be 46,000 pounds or less (reference table 1-1). At a takeoff weight of 52,000 pounds, the aircraft could not attain FL350 assuming an outside air temperature that is standard (ISA). Once the aircraft weighs 50,000 pounds or less, you can attain FL350. In order to attain FL370, the aircraft must weigh 46,000 pounds or less (6,000 pounds less than takeoff weight). These calculations assume a climb at 0.7 Mach. If you choose to climb at a 250 IAS climb, you can increase the weights by 2,000 pounds, but it will take much longer to accelerate once you level off in cruise. As you can see, the aircraft will have to burn approximately 6,000 pounds of fuel before it is able to attain the cruising altitude of FL370. The CRJ 200 burns approximately 2,000 pounds each hour; therefore, the aircraft would not be able to attain the planned cruise altitude until three hours into the flight (most likely at the point when it is time to descend down into KMSP).

The flight crew will have to balance the use of indicated airspeed, true airspeed and Mach number while they operate the aircraft at higher altitudes. Typically, airlines will provide the crews with a "climb profile" to follow to ensure adequate safety margins while maximizing performance.

Recovering Energy at High Altitude

An aircraft operating at high altitude has much less excess thrust available to accelerate or climb. As an aircraft reaches its maximum operating altitude, the rate of climb will diminish to a point where only a 500 feet-per-minute rate of climb is achievable. Additionally, the flight crew will notice a lack of acceleration even when maximum power is applied. Each of these considerations becomes very pertinent when the flight crew wants to recover from low speed or a stalled condition. Low-altitude stall recoveries can be done by applying maximum power, reducing the pitch, and cleaning up the aircraft. Stall recoveries often focus on preventing a loss of altitude—simulating a condition in which the crew is making a low-altitude recovery from a stall. Recovering from a stall at a high altitude will often require a significant loss of altitude. As discussed earlier, the potential energy from the altitude of the aircraft can be translated into kinetic energy in order to recover. For these reasons, a crew must consider altitude loss from a high-altitude stall recovery an acceptable means of recovery.

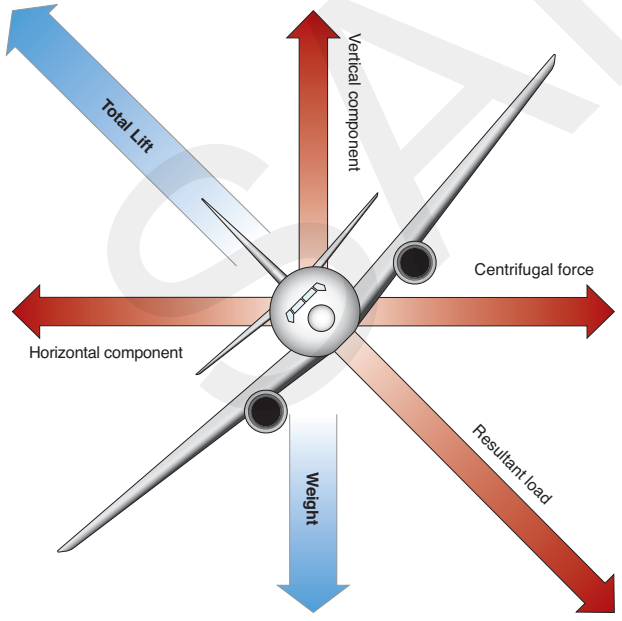


Figure 1-5. Forces in a turn.

Banking in Transport Category Aircraft

Banking an aircraft causes two things to occur: total lift created by the wing is broken into a horizontal component and a vertical component (figure 1-5), and a resultant load is imposed on the aircraft as a result of the centrifugal force caused by the turn. Banking an

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500' CLIMB/CRUISE CAPABILITY

Normal ACU's anti-ice off 25% CG		CL-65 CF34-3B1	Altitude		
A/C weight	OAT	0.70M climb	Cruise speed		
			0.74M	0.77M	0.80M
34000	ISA	41000	41000	41000	41000
	+5	41000	41000	41000	39440
	+10	40400	41000	39920	37710
36000	ISA	41000	41000	41000	40380
	+5	40500	41000	40650	38780
	+10	39500	40710	39220	37090
38000	ISA	40500	41000	41000	39710
	+5	39700	41000	39950	38190
	+10	38700	39980	38580	36520
40000	ISA	39600	41000	40490	39030
	+5	38850	40300	39240	37590
	+10	37950	39230	37950	35520
42000	ISA	38800	41570	39800	38470
	+5	38100	39550	38590	36960
	+10	37200	38540	37310	—
44000	ISA	38000	39800	39100	37890
	+5	37300	38830	37970	36400
	+10	36500	37860	36690	—
46000	ISA	37300	39080	38470	36710
	+5	36600	38170	37330	33580
	+10	36000	37180	36100	—
48000	ISA	36400	38420	37840	36710
	+5	36050	37500	36710	33580
	+10	34700	36550	34730	—
50000	ISA	35800	37760	37200	36090
	+5	34900	36850	36120	31090
	+10	31700	35800	33270	—
52000	ISA	34900	37100	36580	34940
	+5	32200	36240	34970	—
	+10	31000	34710	31420	—

Table 1-1. 500-foot climb/cruise capability.

aircraft at high altitudes will require the pilot to consider each of these factors. First, the resultant load imposed on the aircraft will cause an increase in stall speed. Second, the loss of vertical component of lift will require the pilot to increase the angle of attack (and therefore total lift) in order to maintain altitude. In order to prevent inadvertent stalls during high altitude banks, the flight crew should limit bank angles to 15 degrees or less. The autopilot systems on most transport category aircraft limit the bank angle to 15 degrees above 30,000 feet in order to maintain appropriate separation from the low speed margin of the aircraft. It is also possible that an aircraft operating near the maximum operating altitude will not be able to bank and climb or even maintain altitude. This typically only occurs if the aircraft is fully loaded and very close to the maximum operating altitude.

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At the other end of the spectrum, when an aircraft is descending or at lower altitudes where it can maintain a speed very close to maximum speed, the crew must be aware of the increased load factor caused by banking the aircraft. Transport category aircraft have much lower G-loading limits than normal or utility category aircraft. For this reason, most operators require crews to maintain bank angles of 30 degrees or less for all maneuvering unless a larger bank angle is needed to avoid traffic or terrain. A bank angle of 30 degrees will keep the G-loading low enough that structural damage will not occur, even up to the maximum speed limit of the aircraft.

L/D$_{MAX}$

A discussion on high-altitude aerodynamics would be incomplete if it did not include a discussion on L/D$_{MAX}$. *L/D$_{MAX}$* is a major consideration for pilots operating transport category aircraft at high altitude. L/D$_{MAX}$ is the lowest point on the drag curve (figure 1-6), which corresponds to the airspeed that results in the least amount of drag. An increase or decrease in speed will result in an increase in drag. The minimum drag speed will result in the most efficient operation of an aircraft, but the crew must be aware of the concerns when operating below or very near to this speed.

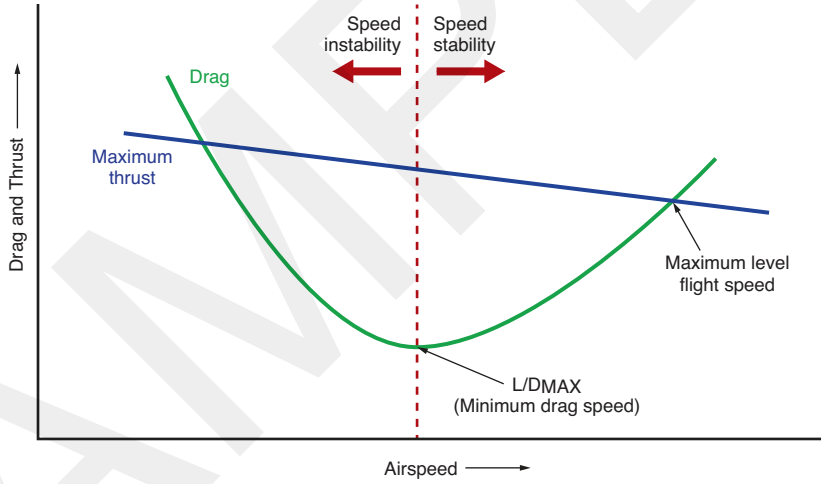


Figure 1-6.
Speed stability.

As shown in figure 1-6, an aircraft operating at a speed below L/D$_{MAX}$ will be operating in a region of speed instability. If an aircraft encounters turbulence while flying in the region of speed instability, the airspeed will continue to decrease unless the crew responds by adding thrust or losing altitude (turning potential energy into kinetic energy). Furthermore, if an aircraft is operating slower than L/D$_{MAX}$ in the region where total drag exceeds total thrust, the airplane will be unable to maintain altitude and the only means of recovery will be to initiate a descent.

When operating at high altitude, it is imperative that flight crews maintain a speed at or above L/D$_{MAX}$, in the region of speed stability. Referring back to figure 1-6, you will notice that a decrease in airspeed in this region will also result in a decrease in drag, thereby allowing the aircraft to return to the previous airspeed without a change in thrust or altitude. With proper flight planning and adherence to published climb profiles, a flight crew can remain in the region of airspeed stability while operating at high altitudes.

SAMPLE

Atmospheric Considerations

The atmosphere varies considerably, especially in the altitudes closest to the ground. The sun heats different bodies (land and water) differently, causing a variation in temperatures and pressures. These variations are typically limited to lower altitudes (below 18,000 feet). This does not mean that differences don't exist at higher altitudes, but the variations there are much less. Most pilots are familiar with the standard atmosphere. This standard was developed as a reference for what the average conditions around the earth normally are. It is rare that these exact conditions exist, but they are a good reference for us to use when comparing one location to another.

As a review, standard atmospheric conditions are defined as 15° Celsius (C) and 29.92 inHg at sea level. Standard conditions at any altitude can be calculated by using a 2°C lapse rate per thousand feet of altitude above sea level. Fortunately, the flight management system (FMS) in most transport category aircraft provides a continuous reading of standard temperature at the current altitude and how different the current temperature is from standard. This reading is typically reported as ISA ±X° (where X is the number of degrees above or below the standard temperature). As an example, consider an aircraft cruising at 37,000 feet with an outside air temperature (OAT) of −49°C. In order to calculate the difference from standard, we need to calculate standard temperature at 37,000 feet using the standard lapse rate of 2°C per 1,000 feet above sea level. 37 multiplied by 2 is 74, indicating that in a standard atmosphere, the temperature would decrease by 74°C from sea level to FL370. Recall that a standard atmosphere is 15°C at sea level, so in order to calculate the standard temperature (referred to as ISA) at 37,000 feet, we need to subtract 74 from 15. This yields a temperature of −59°C. If the current OAT is −49°C, the atmosphere is 10°C warmer than standard. Therefore, the FMS would report the current conditions as ISA + 10°C.

Aerodynamic Ceiling

As already mentioned, the indicated stall speed stays relatively constant as the aircraft gains altitude, while the Mach limit decreases with an increase in altitude, if all other factors remain constant. This creates a converging speed envelope (figure 1-7 on the next page). There is an altitude where the maximum speed limit (Mach limit) and the minimum speed limit (stall speed) meet; this is called the *aerodynamic ceiling*. At this point, the aircraft would be stalling and experiencing some compressibility-induced control problems—not a very good situation in which to be. For that reason, an aircraft's maximum certification ceiling is placed low enough to prevent this condition, but it is still possible for an aircraft to have a narrow window between these limitations (known as "coffin corner"). The aircraft is operating at the top of its maximum operating altitude, and thus the pilots should be very careful in their handling of the aircraft. In fact, flight in this regime should only be done with the autopilot to prevent pilot-induced oscillations. It is also important to understand that the stall speed will increase when the aircraft enters a bank (due to the increased wing loading) and therefore shallow banks are recommended. During a descent from coffin corner, pilots should be careful not to exceed the maximum speed limitation, so a small power reduction may be necessary; the pilot also must be sure not to slow the aircraft to the low speed cue. In essence, the crew must handle the aircraft carefully when operating at or near the aircraft's service ceiling.

Coffin corner is the flight condition in which an increase in airspeed will induce high speed Mach buffet and any decrease in airspeed will induce low speed Mach buffet.

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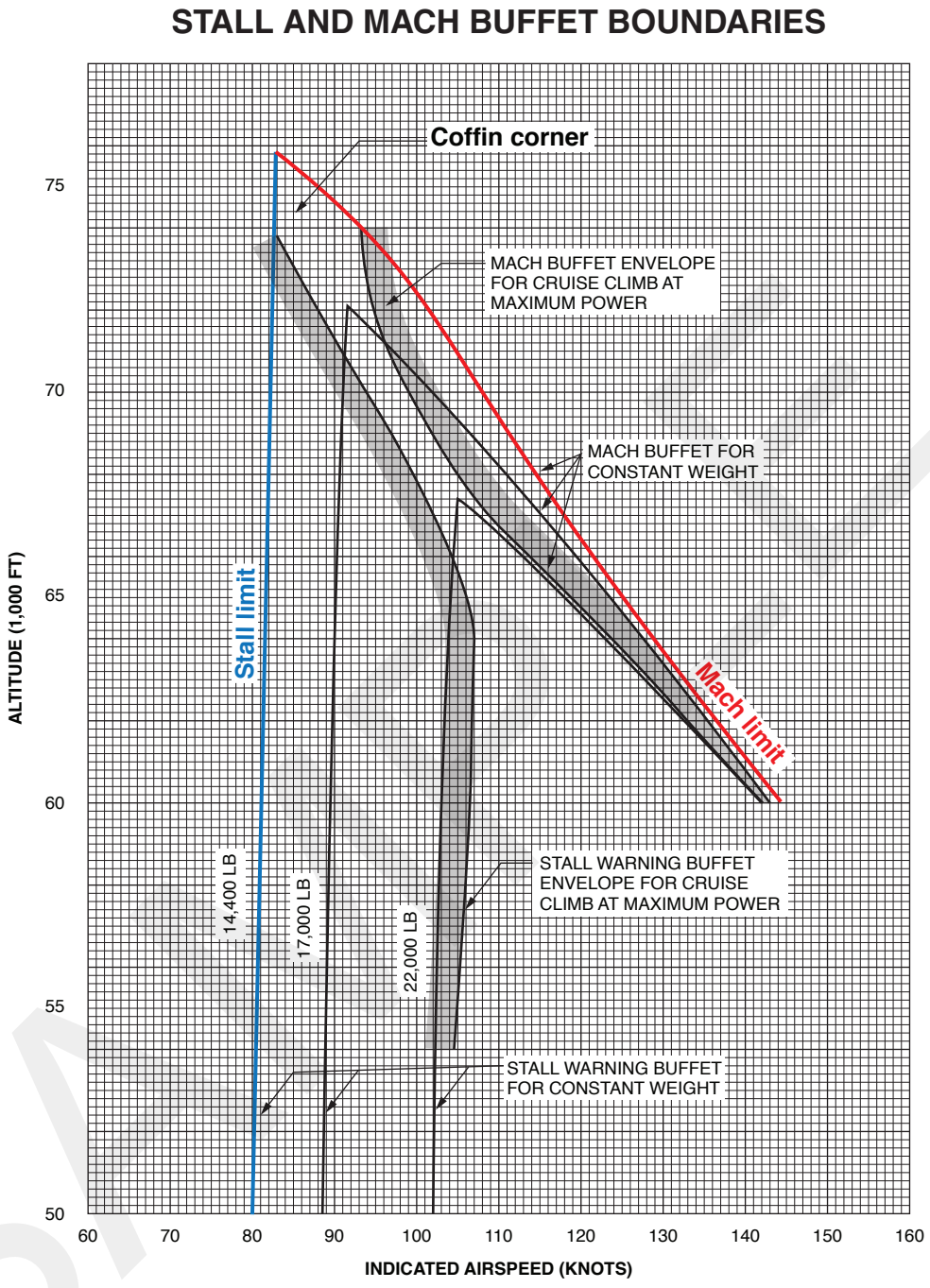


Figure 1-7. Coffin corner.

(Graph of Speed vs. Altitude for U-2 high-altitude airplane; U.S. Air Force photos (https://en.wikipedia.org/wiki/File:CoffinCornerU2.png); Public domain.)

Wing Sweep

As discussed earlier in this chapter, the maximum speed limitation of an aircraft is either a result of dynamic force on the aircraft (V_{MO}) or an aerodynamic limitation resulting from shock wave formation on or near the aircraft (M_{MO}). In an attempt to increase the shock wave-induced speed limitation, aircraft manufacturers use wing sweep (figure 1-8). *Wing sweep* allows an aircraft to fly closer to the speed of sound without experiencing the shock wave-related control problems. An aircraft with high wing sweep will have a higher M_{MO} than an aircraft with no wing sweep. Wing sweep comes at a cost, however, and pilots need to be aware of the operational challenges associated with operating aircraft with high sweep.

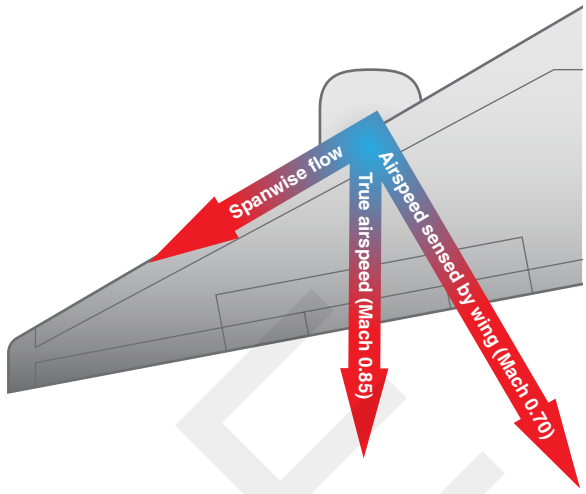


Figure 1-8. Wing sweep.

An aircraft with wing sweep will experience far different stall characteristics than an aircraft with no sweep. A swept-back wing will stall at the wing tips first rather than at the wing root. A wing tip stall creates a lot of control problems for the flight crew, as the effectiveness of the ailerons is severely compromised. High wing sweep also has a negative impact on both lateral and longitudinal stability of the aircraft. As will be discussed in the next section, aircraft with high wing sweep will have a yaw damper to manage directional control, and it will be required to be engaged during all phases of flight (including takeoff and landing).

Dutch Roll

Another negative side effect of swept-wing aircraft is the tendency for Dutch roll. *Dutch roll* is a combination of yaw and bank that oscillates back and forth, typically worsening over time. A swept-wing aircraft has positive static lateral stability. When a swept-wing aircraft is placed in a sideslip (through improper coordination during a turn or by turbulence), the wing into the wind will create more lift while the downwind wing will create less lift, which will cause a roll back towards level flight (positive static stability). However, a swept-wing aircraft will typically overcorrect and go beyond level bank before returning the other direction (negative dynamic stability). In this case, adverse yaw may result in a worsening yaw and bank over time if the flight crew does not apply recovery techniques. For this reason, most transport category aircraft with high wing sweep will incorporate a yaw damper, which will ensure that yaw corrections are made early and often in order to prevent overcorrection.

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