High Altitude Operations

Supplement #1 to the Airplane Upset Recovery Training Aid

Assembled by the Industry Airplane Upset Recovery Training Aid Team, October 5, 2008

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Introduction

This document is intended to supplement the Airplane Upset Recovery Training Aid Rev 1 that was released in August 2004. It addresses the issues associated with operations, unintentional slowdowns, and recoveries in the high altitude environment. While the Airplane Upset Recovery Training Aid addressed airplanes with 100 seats or greater, the information in this document is directly applicable to most all jet airplanes that routinely operate in this environment. This information has also been inserted in the Airplane Upset Recovery Training Aid Rev 2 completed October 2008. Consult the operations manual for your airplane type, as that information takes precedent to the following guidance.

An industry working group was formed to develop this guidance at the request of the U.S. Department of Transportation, Federal Aviation Administration. The working group consisted, in scope, of both domestic and international organizational representatives from the airline, manufacturer, regulatory, industry trade, and educational segments. The goal of this group was to educate pilots so they have the knowledge and skill to adequately operate their airplanes and prevent upsets in a high altitude environment. This should include the ability to recognize and prevent an impending high altitude problem and increase the likelihood of a successful recovery from a high altitude upset situation should it occur.

This working group was formed as a result of the United States National Transportation Safety Board (NTSB) recommendations from a high altitude loss of control accident and other recent accidents and incidents that have occurred under similar conditions. The NTSB recommendations stated that pilots should possess a thorough understanding of the airplane's performance capabilities, limitations, and high altitude aerodynamics. The guidance in this document is intended to supplement the Airplane Upset Recovery Training Aid in these areas.

There have been other recent accidents where for various reasons (e.g. trying to top thunderstorms, icing equipment performance degradation, unfamiliarity with high altitude performance, etc.) crews have gotten into a high altitude slowdown situation that resulted in a stalled condition from which they did not recover. There have been situations where for many reasons (e.g. complacency, inappropriate automation modes, atmospheric changes, etc.) crews got into situations where they received an approach to stall warning. Some of the recoveries from these warnings did not go well. This supplement is intended to discuss these possible situations, and provide guidance on appropriate training and recommendations for knowledge, recognition, and recovery.

For example, a recent incident occurred where an airplane experienced an environmental situation where airspeed slowly decayed at altitude. The crew only selected maximum cruise thrust, instead of maximum available thrust, and that did not arrest the slowdown. The crew decided to descend but delayed to get ATC clearance. Airplane slow speed buffet started, the crew selected an inappropriate automation mode, the throttles were inadvertently reduced to idle, and the situation decayed into a large uncontrolled altitude loss. This incident may easily have been prevented had the flight crew acted with knowledge of information and techniques as contained in this supplement.

In another high altitude situation, the crew decided to use heading select mode to avoid weather while experiencing turbulence. The steep bank angle that resulted from this mode quickly caused slow speed buffeting. The crew's rapid inappropriate response to disconnect the autopilot and over-control the airplane into a rapid descent in poor weather exacerbated the situation. These real world examples provide evidence towards the need for more detailed training in high altitude operations.

High Altitude Aerodynamics

To cope with high altitude operations and prevent upset conditions, it is essential to have a good understanding of high altitude aerodynamics. This section represents terms and issues pilots need to understand thoroughly in order to successfully avoid upset conditions or cope with inadvertent encounters.

As a purely practical matter, it is useful to identify high altitude operations as those above flight level 250 (FL250 or 25,000 feet). The great majority of passengers and freight is now being carried in turbojet-powered airplanes, virtually all of which regularly operate at altitudes above FL250 where high speeds and best economy are attained. While aerodynamic principles and certain hazards apply at all altitudes, they become particularly significant with respect to loss of control (or upset) at altitudes above FL250. For these reasons and others, this training aid defines high altitude as any altitude above FL250.

High Altitude Operations -Regulatory Issues

The high altitude environment has a number of specific references within regulations. They include: criteria defining maximum operating altitude and service ceilings, required high altitude training, flight crew member use of oxygen, passenger briefings, airspace issues, transponder usage, and Reduced Vertical Separation Minimum (RVSM) requirements. Although this information is necessary knowledge for flight crews, this document will focus on the information necessary to prevent and recover from upsets in the high altitude environment.

There are a number of aerodynamic principles that are necessary to understand to have a good grasp of high altitude performance.

L/D Max

The lowest point on the total drag curve (as indicated in figure 1) is known as L/D max (or Vmd-minimum drag speed). The speed range slower than L/D max is known as slow flight, which is sometimes referred-to as the "back side of the power-drag curve" or the "region of reverse command". Speed faster than L/D max is considered normal flight, or the "front side of the power-drag curve".

Normal flight (faster than L/D max) is inherently stable with respect to speed. When operating in level flight at a constant airspeed with constant thrust setting, any airspeed disturbance (such as turbulence) will result in the airspeed eventually returning to the original airspeed when the total thrust has not changed.

Slow flight (slower than L/D max) is inherently unstable with respect to speed and thrust settings. When operating at a constant airspeed with constant thrust setting, any disturbance causing a decrease in airspeed will result in a further decrease in airspeed unless thrust is increased. As in Figure 1, the lower speed will subject the airplane to increased drag. This increase in drag will cause a further decrease in airspeed, which may ultimately result in a stalled flight condition. Flight slower than L/D max at high altitudes must be avoided due to the inefficiency and inherent instability of the slow flight speed range. When operating slower than L/D max, and where total drag exceeds total thrust, the airplane

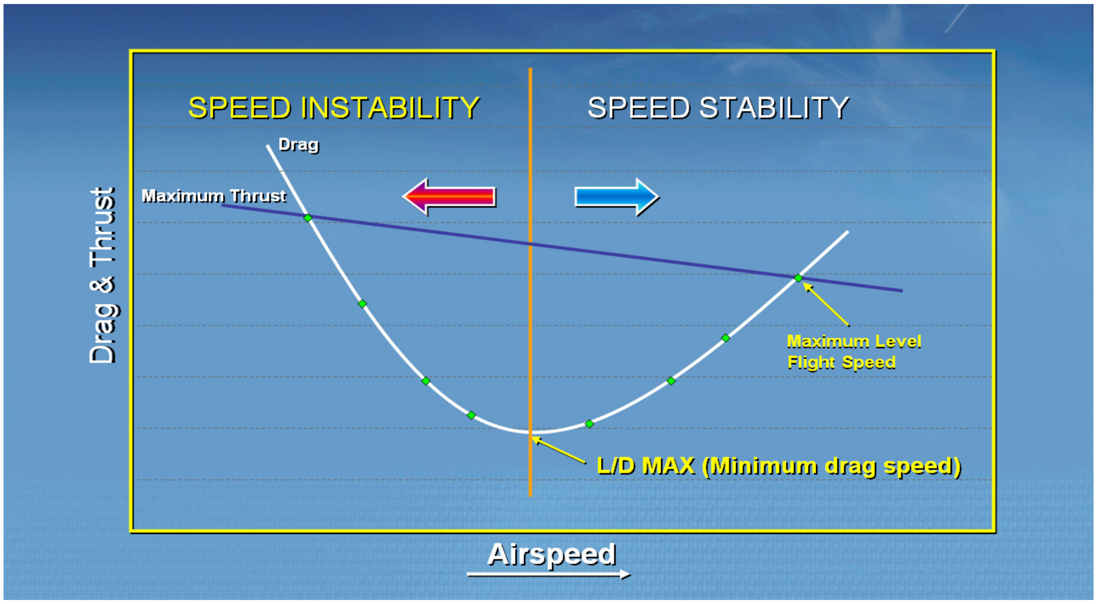

Figure 1. Airspeed versus drag in level flight

will be unable to maintain altitude and the only remaining option to exit the slow flight regime is to initiate a descent.

External factors, such as changing winds, increased drag in turns, turbulence, icing or internal factors, such as anti-ice use, auto-throttle rollback, or engine malfunction or failure can cause airspeed decay. Heavily damped auto-throttles, designed for passenger comfort, may not apply thrust aggressively enough to prevent a slowdown below L/D max.

Slower cruising speeds are an issue. As airplanes are pushed to more efficient flight profiles to save fuel, it may dictate high altitude cruising at lower Mach numbers. The net result is the crew may have less time to recognize and respond to speed deterioration at altitude.

At all times, pilots must ensure that flight slower than L/D max is avoided in the high altitude environment. Proper flight planning and adherence to published climb profiles and cruise speeds will ensure that speeds slower than L/D max are avoided.

As an airplane climbs and cruises at high altitude, flight crews should be aware of terms that affect them.

Crossover Altitude

Crossover Altitude is the altitude at which a specified CAS (Calibrated airspeed) and Mach value represent the same TAS (True airspeed) value. Above this altitude the Mach number is used to reference speeds.

Optimum Altitude

Optimum Altitude is defined as an altitude at which the equivalent airspeed for a thrust setting will equal the square root of the coefficient of lift over the coefficient of drag. In less technical terms, it is the best cruise altitude for a given weight and air temperature. A dramatic increase in temperature will lower the optimum altitude. Therefore, when flying at optimum altitude, crews should be aware of temperature to ensure performance capability.

Optimum Climb Speed Deviations

Airplane manuals and flight management systems produce optimum climb speed charts and speeds. When increased rates of climb are required, ensure speed is not decreased below L/D max. Evidence shows that inappropriate use of vertical speed modes is involved in the majority of slow speed events during high altitude climbs.

Thrust Limited Condition and Recovery

Most jet transport airplanes are thrust limited, rather than low speed buffet limited, at altitude, especially in a turn. It is imperative that crews be aware of outside temperature and thrust available. To avoid losing airspeed due to a thrust limit, use flight management systems/reduced bank angle as a routine for en-route flight if it incorporates real-time bank angle protection, or routinely select a bank angle limit of 10-15 degrees for cruise flight. If a condition of airspeed decay occurs at altitude, take immediate action to recover:

- Reduce bank angle
- Increase thrust – select maximum continuous thrust if the airplane's auto-throttle system is maintaining thrust at a lower limit
- Descend

If a high drag situation occurs where maximum available thrust will not arrest the airspeed decay, the only available option is to descend.

Maximum Altitude

Maximum altitude is the highest altitude at which an airplane can be operated. In today's modern airplanes it is determined by three basic characteristics which are unique to each airplane model. It is the lowest of:

- Maximum certified altitude (structural) that is determined during certification and is usually set by the pressurization load limits on the fuselage.
- Thrust Limited Altitude – the altitude at which sufficient thrust is available to provide a specific minimum rate of climb.
- Buffet or Maneuver limited altitude – the altitude at which a specific maneuver margin exists prior to buffet onset.

Although each of these limits is checked by modern flight management computers the available thrust may limit the ability to accomplish anything other than relatively minor maneuvering.

The danger in operating near these ceilings is the potential for the speed and angle of attack to change due to turbulence or environmental factors that could lead to a slowdown or stall and subsequent high altitude upset.

In early turbojet era airplanes the capability to reach what is called absolute ceiling or "coffin corner" could exist. This is where if an airplane flew any slower it would exceed its stalling angle of attack and experience low speed buffet. Additionally, if it flew any faster it would exceed Mmo, potentially leading to high speed buffet.

All airplanes are equipped with some form of stall warning system. Crews must be aware of systems installed on their airplanes (stick pushers, shakers, audio alarms, etc.) and their intended function. In a high altitude environment, airplane buffet is sometimes the initial indicator of problems.

Maneuvering Stability

For the same control surface movement at constant airspeed, an airplane at 35,000 ft experiences a higher pitch rate than an airplane at 5,000 ft because there is less aerodynamic damping. Therefore, the change in angle of attack is greater, creating more lift and a higher load factor. If the control system is designed to provide a fixed ratio of control force to elevator deflection, it will take less force to generate the same load factor as altitude increases.

An additional effect is that for a given attitude change, the change in rate of climb is proportional to the true airspeed. Thus, for an attitude change for 500 ft per minute (fpm) at 290 knots indicated air speed (KIAS) at sea level, the same change in attitude at 290 KIAS (490 knots true air speed) at 35,000 ft would be almost 900 fpm. This characteristic is essentially true for small attitude changes, such as the kind used to hold altitude. It is also why smooth and small control inputs are required at high altitude, particularly when disconnecting the autopilot.

Operating limits of modern transport category airplanes are designed so that operations within these limits will be free of adverse handling characteristics. Exceeding these limits can occur for various reasons and all modern transport airplanes are tested to allow normal piloting skill to recover these temporary exceedences back to the normal operational envelope. It is imperative to not overreact with large and drastic inputs. There is no need to take quick drastic action or immediately disconnect a correctly functioning autopilot. Pilots should smoothly adjust pitch and/or power to reduce speed should an overspeed occur.

In the high altitude flight area there is normally adequate maneuver margin at optimum altitude. Maneuver margin decreases significantly as the pilot approaches maximum altitude. Flying near maximum altitude will result in reduced bank angle capability; therefore, autopilot or crew inputs must be kept below buffet thresholds. The use of LNAV will ensure bank angle is limited to respect buffet and thrust margins. The use of other automation modes, or hand flying, may cause a bank angle that result in buffeting. When maneuvering at or near maximum altitude there may be insufficient thrust to maintain altitude and airspeed. The airplane may initially be within the buffet limits but does not have sufficient thrust to maintain the necessary airspeed. This is a common item in many high altitude situations where airplanes slow down to the lower buffet limits. These situations can be illustrated with performance charts.

Figure 2 shows a typical transport category airplane optimum and maximum altitude capability. When temperature increases the maximum altitude capability decreases significantly. This is a situation where maneuver buffet margins are adequate but temperature is affecting thrust capability to sustain airspeed at the higher altitudes.

Figure 3 shows that for normal cruise speeds there is excess thrust available at this fixed weight and altitude. When trying to turn using 30 degrees of bank, the drag exceeds the normal maximum cruise thrust limit. If the pilot selects maximum continuous thrust (MCT) then there is enough thrust to maintain the bank angle in the same situation.

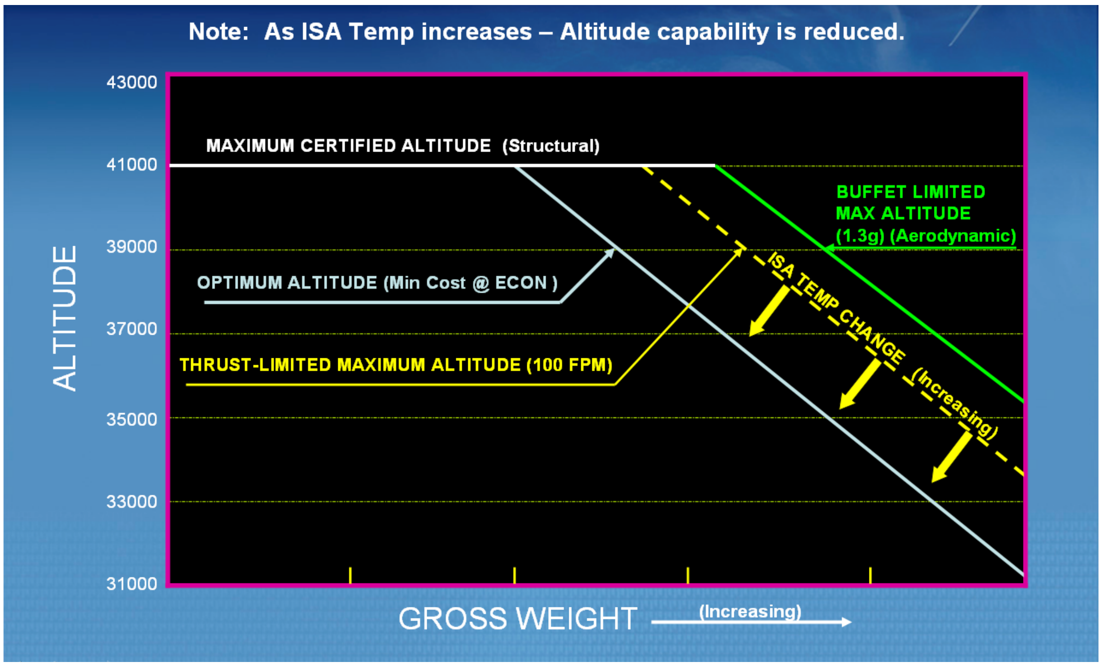

Figure 2. Typical optimum versus maximum altitude

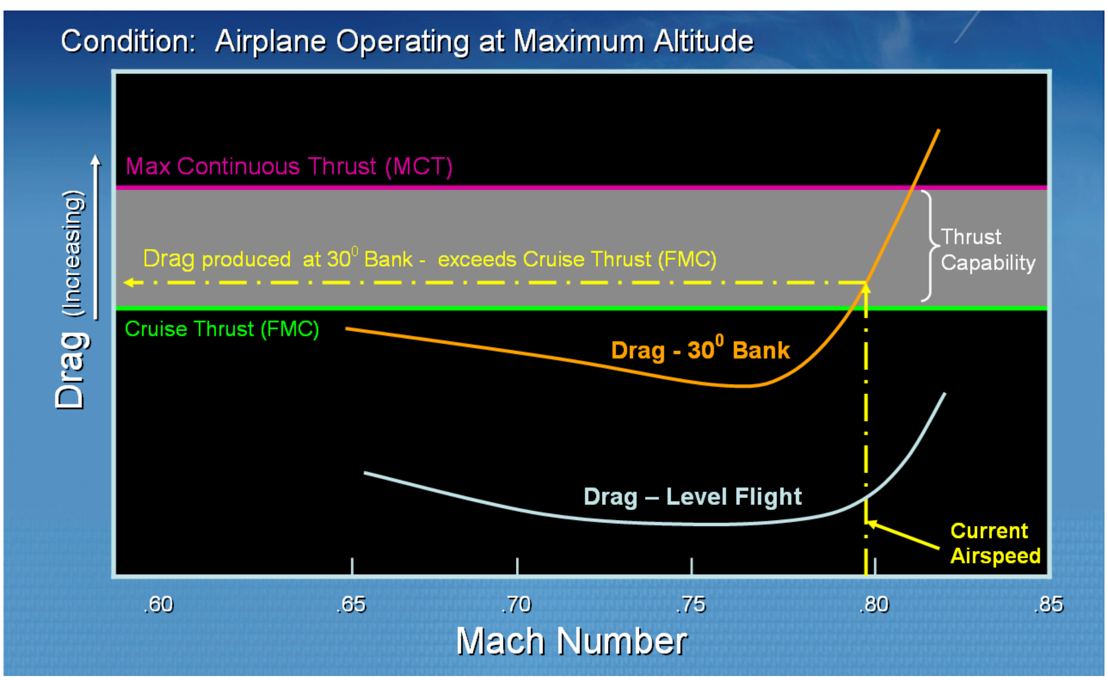

Figure 3. Drag reduced by bank versus available thrust

Weight & Balance Effects on Handling Characteristics

Weight and Balance limitations must be respected. An airplane that is loaded outside the weight and balance envelope will not exhibit the expected level of stability and will result in aircraft handling that is unpredictable and may not meet certification requirements. This is a serious issue, particularly in an aft loading situation where stall recovery may be severely affected. The problem may be exacerbated at high altitude.

At high altitude, an aft loaded airplane will be more responsive to control pressures since it is less stable than a forward loading. Of interest to pilots is that the further aft an airplane is loaded, less effort is required by the tail to counteract the nose down pitching moment of the wing. The less effort required by the tail results in less induced drag on the entire airplane which results in the most efficient flight. Some airline load planning computers attempt to load airplane as far aft as possible to achieve efficiency. Some advanced airplanes use electronic controls to help improve airplane handling with aft loading.

Mach Tuck and Mach Buffet

In some airplanes, at speeds above Mmo, a phenomenon called mach tuck will occur. Above critical Mach number the speed of an airplane at which airflow over any part of the wing first reaches Mach 1.0 a shock wave will begin to form on the wing and mach buffet will occur. Mach buffet will continue to increase with increased speed and the aft movement of the shock wave, the wing's center of pressure also moves aft causing the start of a nose-down tendency or "tuck." Because of the changing center of lift of the wing resulting from the movement of the shock wave, the pilot will experience pitch down tendencies. In modern transport airplanes this phenomenon has been largely eliminated.

Buffet-Limited Maximum Altitude

There are two kinds of buffet to consider in flight; low speed buffet and high speed buffet. As altitude increases, the indicated airspeed at which low speed buffet occurs increases. As altitude increases, high speed buffet speed decreases. Therefore, at a given weight, as altitude increases, the margin between high speed and low speed buffet decreases.

Proper use of buffet boundary charts or maneuver capability charts can allow the crew to determine the maximum altitude that can be flown while still respecting the required buffet margins.

At high altitudes the excess thrust available is limited. Crews must be aware that additional thrust is available by selecting maximum available/continuous thrust at any time. However, in extreme airspeed decay situations MCT may be insufficient. Proper descent techniques will be necessary in order to prevent further airspeed decay into an approach to stall and stall situation.

Stalls

Fundamental to understanding angle of attack and stalls is the realization that an airplane wing can be stalled at any airspeed and any altitude. Moreover, attitude has no relationship to the aerodynamic stall. Even if the airplane is in descent with what appears like ample airspeed, the wing surface can be stalled. If the angle of attack is greater than the stall angle, the surface will stall.

Most pilots are experienced in simulator or even airplane exercises that involve approach to stall. This is a dramatically different condition than a recovery from an actual stall because the technique is not the same. The present approach to stall technique being taught for testing is focused on "powering" out of the near-stalled condition with emphasis on minimum loss of altitude. At high altitude this technique may be totally inadequate due to the lack of excess thrust. It is impossible to recover from a stalled condition without reducing the angle of attack and that will certainly result in a loss of altitude, regardless of how close the airplane is to the ground. Although the thrust vector may supplement the recovery it is not the primary control. At stall angles of attack, the drag is very high and thrust available may be marginal. Also, if the engine(s) are at idle, the acceleration could be very slow, thus extending the recovery. At high altitudes, where the available thrust is reduced, it is even less of a benefit to the pilot. The elevator is the primary control to recover from a stalled condition, because, without reducing the angle of attack, the airplane will remain in a stalled condition until ground impact, regardless of the altitude at which it started.

Effective stall recovery requires a deliberate and smooth reduction in wing angle of attack. The elevator is the primary pitch control in all flight conditions, not thrust.

Altitude Exchange For Airspeed

Although stall angle of attack is normally constant for a given configuration, at high altitudes swept wing turbojet airplanes may stall at a reduced angle of attack due to Mach effects. The pitch attitude will also be significantly lower than what is experienced at lower altitudes. Low speed buffet will likely precede an impending stall. Thrust available to supplement the recovery will be dramatically reduced and the pitch control through elevator must be used. The goal of minimizing altitude loss must be secondary to recovering from the stall. Flight crews must exchange altitude for airspeed. Only after positive stall recovery has been achieved, can altitude recovery be prioritized.

An airplane is stalled when the angle of attack is beyond the stalling angle. A stall is characterized by any of, or a combination of, the following:

a. Buffeting, which could be heavy at times
b. A lack of pitch authority
c. A lack of roll control.
d. Inability to arrest descent rate.

These characteristics are usually accompanied by a continuous stall warning.

Weather effects that could cause a slowdown or stall at high altitudes

At high altitudes the upper air currents such as the jet-stream become significant. Velocities in the jet-stream can be very high and can present a beneficial tailwind or a troublesome headwind. Windshear at the boundaries of the jet-stream can cause severe turbulence and unexpected changes in airspeed or Mach number. This windshear, or other local disturbances, can cause substantial and immediate airspeed decreases in cruise, as well as climb situations. If the airplane is performance limited due to high altitude and subsequently encounters an area of decreasing velocity due to wind shear, in severe cases the back side of the power curve may be encountered. The pilot will have to either increase thrust or decrease angle of attack to allow the airspeed to build back to normal climb/cruise speeds. This may require trading altitude for airspeed to accelerate out of the backside of the power curve region if additional thrust is not available.

ICING – Use of Anti-Ice on Performance

Pilots must understand that occasionally icing does occur at high altitudes and they must be prepared to use anti-ice. Careful monitoring of flight conditions is critical in this decision making.

Appropriate and judicious use of anti-ice equipment at high altitude is very important. One must be aware of the fact that the use of anti-ice has a negative effect on the available thrust. In some cases, it may not be possible to maintain cruise speed or cruise altitude at high altitude with anti-ice on. Pilots should also be aware of the specific flight planning parameters for their particular flight.

In-flight Icing Stall Margins

In-flight icing is a serious hazard. It destroys the smooth flow of air on the airplane, increasing drag, degrading control authority and decreasing the ability of an airfoil to produce lift. The airplane may stall at much higher speeds and lower angles of attack than normal. If stalled, the airplane can roll or pitch uncontrollably, leading to an in-flight upset situation.

Even with normal ice protection systems operating properly, ice accretion on unprotected areas of the airplane may significantly increase airplane weight and drag.

Activation of an artificial stall warning device, such as a stick shaker, is typically based on a pre-set angle of attack. This setting gives a warning prior to actual stall onset where buffeting or shaking of the airplane occurs. For a clean airplane, the pilot has adequate warning of impending stall. However, with ice, an airplane may exhibit stall onset characteristics before stick shaker activation because of the effect of ice formations on reducing the stall angle-of-attack. In this case, the pilot does not have the benefit of a stick shaker or other stall warning.

Flight crews must be especially wary of automation during icing encounters. Autopilots and autothrottles can mask the effects of airframe icing and this can contribute to ultimate loss of control. There have been several accidents in which the autopilot trimmed the airplane right to a stall upset situation by masking heavy control forces. If the autopilot disengages while holding a large roll command to compensate for an asymmetric icing condition (or other similar problem causing roll), an immediate large rolling moment ensues for which the pilot may not be prepared, resulting in a roll upset. Pilots have been surprised when the autopilot automatically disconnected with the airplane on the brink of a stall.

Some autopilots are designed with control laws that enable them to continue to operate until they get to stick shaker. Alternatively, the autopilot may disconnect early because of excessive roll rates, roll angles, control surface deflection rates, or forces that are not normal. These autopilots are not malfunctioning; they are working as designed.

High altitude weather can cause favorable conditions for upsets. Thunderstorms, clear air turbulence, and icing are examples of significant weather that pilots should take into consideration in flight planning. Careful review of forecasts, significant weather charts, turbulence plots are key elements in avoiding conditions that could lead to an upset.

Once established in cruise flight, the prudent crew will update weather information for the destination and enroute. By comparing the updated information to the preflight briefing, the crew can more accurately determine if the forecast charts are accurate. Areas of expected turbulence should be carefully plotted and avoided if reports of severe turbulence are received. Trend monitoring of turbulence areas is also important. Trends of increasing turbulence should be noted and if possible avoided. Avoiding areas of potential turbulence will reduce the risk of an upset.

Primary Flight Display Airspeed Indications

Modern airplanes that are equipped with a primary flight display (PFD) provide information that will help maintain a safe airspeed margin between the low and high speed limits. Most of these airplanes have an indication of airspeed trending. This is important because these displays do not indicate if adequate thrust is available at that altitude to maintain the current airspeed. Older airplanes have charts in the performance section that depict adequate speed ranges for a given altitude and weight.

Flight Techniques of Jet Aircraft

Now that we are familiar with terms and aerodynamics of high altitude operations, certain techniques will now be discussed that will aid in eliminating high altitude upsets.

Automation During High Altitude Flight

During cruise at high altitude the autopilot will be engaged with the pitch in an altitude hold mode and the throttles in a speed mode. However, it is possible that due to changing conditions (increasing temperature, mountain wave, etc.) or poor planning, an airplane could be thrust limited and not be able to maintain the desired altitude and/or airspeed. Regardless, the airplane's automatic control system will try to maintain this altitude by increasing thrust to its selected limit. When the thrust is at the maximum limit the pitch may continue to increase to maintain altitude and the airspeed then continues to decay. The only option then is to descend. The pilot's action should be to pitch down and increase the airspeed while being in an automation mode that keeps the throttles at maximum thrust. If the autopilot is still engaged, select a lower altitude and use an appropriate mode to start the aircraft down. However, if the aircraft is not responding quickly enough you must take over manually. Pilots must assess the rate at which vertical speed and airspeed increase is occurring to make this determination. This does not imply that aggressive control inputs are necessary. The autopilot can then be reengaged once the airplane is in a stable descent and the commanded speed has been reestablished. Do not attempt to override the autopilot, it is always better to disconnect it before making manual control inputs. Due to RVSM considerations and large altitude losses, crews should consider turning off course during descents and monitoring TCAS to reduce the potential for collisions. Crews should also inform ATC of their altitude deviations.

The consequences of using Vertical Speed (VS) at high altitude must be clearly understood. Most autoflight systems have the same logic for prioritizing flight path parameters. The fundamental aspect of energy management is to manage speed by either elevator or with thrust. When using the VS mode of the Auto Flight System (AFS), airplane speed is normally controlled by thrust. If a too high vertical descent rate is selected the autothrottle will reduce thrust to idle and the airspeed will start to increase above the commanded airspeed. The reverse situation can occur with considerable risk if an excessive climb rate is selected. In that case, if the thrust available is less than the thrust required for that selected vertical speed rate the commanded speed will not be able to be held and a speed decay will result. On some airplanes, improper use of VS can result in speed loss and eventually a stall.

Pilots must understand the limits of their airplanes when selecting vertical modes. As a general guideline, VS should not be used for climbing at high altitudes. Reduced thrust available at high altitudes means that speed should be controlled through pitch and not with thrust. VS can be used for descent; however, selecting excessive vertical speeds can result in airspeed increases into an overspeed condition. Using a mode that normally reduces thrust, when the need arises to descend immediately, may not be appropriate for a low speed situation. Either disconnect autothrottles, or use a mode that keeps the throttles at maximum available thrust in these situations.

Human Factors and High Altitude Upsets

The flightcrew may be startled by unexpected low airspeed stall warnings, dynamic buffeting and large changes in airplane attitude (design dependent) especially when the airplane is on autopilot. While flightcrews receive training on systems such as stick shakers to alert the pilots of impending stall, normally they do not receive training in actual full stall recovery, let alone stall recovery at high altitudes. Hence, flight crews are inclined to respond to high altitude stalls like they have been trained to respond to stall warnings, but the procedures for the latter are neither effective nor proper for stall recovery. Furthermore, unlike the conditions for which the flightcrew is trained to respond to stall warnings at lower altitudes, at the higher altitudes the available thrust is insufficient, alone, to recover from a stall. The only effective response is to reduce the angle of attack and trade altitude for airspeed. Pilots have also reported that low airspeed buffet was mistaken for high speed buffet which prompts an incorrect response to reduce airspeed when approaching a low airspeed stall. As in any emergency situation, if the airplane is designed with effective alerting (actual and/or artificial) and the flightcrew is adequately trained to recognize the indicators of the stall, these will lead to appropriate flight crew recovery actions as discussed in the next paragraph. Equally important is that crews be familiar with stall warning and recognition devices, such as stick pushers, in order to understand their operation.

Once the pilot recognizes the airplane is in a full aerodynamic stall, immediate corrective actions and decisions required for airplane recovery are sometimes delayed by the flightcrew. Some of the reasons for the delay include 1) lack of situational awareness and crew confusion, 2) anxiety associated with altitude violations and maintaining separation from other air traffic, 3) previous training emphasizing prevention of altitude loss of only a few hundred feet even in the case of an impending high altitude stall, 4) inadequate experience with high altitude manual flight control, and 5) concern for passenger and crew safety. While the magnitude of required flight control input will vary by airplane design for recovery, flightcrews should be trained to expect a longer recovery time and greater altitude loss, often thousands of feet, while the airplane accelerates to gain airspeed following high altitude stall

Also, since there is no detailed checklist or procedure telling the pilot when to start the stall recovery and how much back pressure should be used for return to level flight after stall recovery, these techniques need to be adequately trained. For example during stall recovery, pilots gauge how assertively they can pull back by using stick shaker activation to indicate when to reduce back pressure. Other pilots may use angle of attack limit indications on the attitude indicator (if equipped) to aid in the stall recovery. Pilots should also be aware that an aggressive stall recovery and subsequent altitude recapture can result in a secondary stall during stall recovery as the pilot discovers the correct level of control inputs required to recover the airplane. On the other side there is the concern of accelerating into high speed buffet during the recovery if the airplane is allowed to accelerate too much.

Additional Considerations

Multi-Engine Flame Out

At high altitudes, as a result of very low airspeed, stall conditions, or other occurrences an all engine flameout may occur. This is easily detected in cruise but may be more difficult to detect during a descent. The all engine flameout demands prompt action regardless of altitude and airspeed. After recognition, immediate accomplishment of the recall items and/or checklist associated with the loss of all engines is necessary to quickly establish the appropriate airspeed (requires a manual pitch down) and to attempt a windmill relight. It should be noted that loss of thrust at higher altitudes (above 30,000 feet) may require driftdown to a lower altitude to improve windmill starting capability. Additionally, even though the inflight start envelope is provided to identify the region where windmill starts can occur, it is often demonstrated during certification this envelope does not define the only areas where a windmill start may be successful. Regardless of the conditions and status of the airplane, strict adherence to the checklist is essential to maximize the probability of a successful relight.

Core Lock

Core lock is a phenomenon that could, in theory, occur in any turbine engine after an abnormal thermal event (e.g. a sudden flameout at low airspeed) where the internal friction exceeds the external aerodynamic driving forces and the “core” of the engine stops. When this occurs, differential contraction of the cooler outside case clamps down on the hotter internal components (seals, blade tips etc.) preventing rotation or “locking the core.” This seizure may be severe enough to exceed the driving force available by increasing airspeed or from the starter. If differential cooling locks the core, only time will allow the temperature difference to equalize, reduce the contact friction caused by differential contraction and allow free rotation.

After all engine flameouts, the first critical item is to obtain safe descent speed. Then flight crews need to determine engine status. If any of the engine spools indicate zero RPM then a situation of core lock may exist or mechanical engine damage could have occurred. If this case applies to all engines, crews must obtain best L/D airspeed instead of accelerating to windmill speed, to obtain an optimum glide ratio. Crews then should consider their forced landing options. In the event the seized spool(s) begin to rotate a relight will be contemplated and windmill airspeed may be necessary.

Rollback

Turbine engine rollback is an uncommon anomaly consisting of an uncommanded loss of thrust (decrease in EPR or N1), which is sometimes accompanied by an increase in EGT. Rollback can be caused by a combination of many events including moisture, icing, fuel control issues, high angle of attack disrupted airflow, and mechanical failure and usually results in flameout or core lockup. Modern airplanes alleviate most rollback issues with autorelight. Additionally, updated progressive maintenance programs identify potential problems and help to decrease rollback events. It is conceivable that pilots would recognize the results of rollback rather than the rollback event itself depending on workload and flight experience. If airspeed stagnation occurs, checking of appropriate thrust levels is important as well as increasing airspeed in the case where an engine has rolled back.

High Altitude Loft Scenario

The following example loft scenario is recommended by industry as a way of familiarizing crews with high altitude slowdowns and approach to stall. Crews should always recover at the first indication of an impending stall. Operators may want to modify this scenario for the specific airplane models flown.

High Altitude Stall Warning

Lesson:	High Altitude Stall Warning	**Performance Package:**	TBD
Lesson Type:	Train to Proficiency	**Pre-Brief Time:**	TBD
Minimum Device:	Full Flight Simulator	**Preparation Time:**	TBD
		Sim Time	TBD
		Preparations Time:	TBD
		De-Brief Time:	TBD

Introduction:	The purpose of this LOFT training aid is to assist operators of high altitude jet airplanes. The high altitude slowdown to an approach to stall represents a threat that has resulted in accidents and incidents when mismanaged. This simulator training is to assist crews in managing this threat. The exercise is not intended to train an actual jet upset or full stall, it only has the airplane reach the indications of an approach to stall before a recovery is initiated. Operators should consider a number of factors to determine how realistic their simulator will respond to this training scenario. Operators should determine the optimum manner to set up this scenario to achieve the goals of the training.
Goals of Training:	1. Reinforce understanding of applicable high altitude characteristics 2. Assess how to determine cruise altitude capability 3. Reinforce acceptable climb techniques and acknowledge the risks associated with various climb scenarios and in particular vertical speed 4. Recognize cues of an approach to stall and indications observable prior to that point 5. Discuss automation factors such as mode protections, hazards of split automation (where either autopilot or autothrottle is disconnected) and inappropriate modes 6. Address intuitive and incorrect reactions to stall warning indications 7. Develop procedures that are widely accepted to recover from impending high altitude stall conditions with and without auto-flight systems
Introductory Notes:	The crew begins this lesson in cruise flight with an airplane at an altitude of FL250 or above in a near maximum altitude situation. The airplane weight should be at or near the maximum for that altitude based upon company or manufacturer's procedures. The crew should discuss performance capability and reference applicable resources to determine what the maximum altitude is for the weight and environmental conditions. These references could include cruise charts, FMS optimum and FMS maximum altitudes with various mode protections (lateral and vertical) available. Buffet margins should be referenced and discussed based on the altitude. Alternative climbing modes and their associated hazards should be understood. Common errors include complacency with climb and cruise procedures as well as a lack of knowledge with cruise charts.

Setup and Limitations:	The simulator will then be either positioned or flown inappropriately to a situation where with an increase in ISA temperature will cause the airplane to be behind the power curve due to changing ambient conditions. The early addition of maximum available thrust should be discussed as a necessity to prevent this situation from occurring. However, in this situation maximum thrust is not enough to keep from slowing down while maintaining altitude. Certain airplane features, either with automation or without, may prevent an approach to stall from occurring. However, indications of such an impending situation should be discussed. These include airspeed trends, symbology/warning changes, low speed indications, trim changes, etc. Auto thrust or autopilot may have to be disconnected to provide the approach to stall indications, but the goal should be to keep those modes in operation if possible to simulate a real scenario. Instructors should discuss the system degradation that results in this situation and the associated hazards. If unable to produce desired effect, reducing thrust may be necessary.
Recognition and Recovery	Brief interactive discussions of impending stall warning recovery methods followed by an actual stall warning recovery. Instructors should ensure the crews recover at the first indication of an approach to stall (mode reversions, aural; shaker, pusher warnings, buffet, etc). Do not allow the airplane to stall or the situation to progress to an upset situation because simulator realism may be compromised in this condition. Emphasis should be placed that the recovery requires maximum thrust and the reduction of pitch to lower the angle of attack and allowing the airplane to accelerate. At these altitudes and weight/temperature combinations, a descent will be required. If the autoflight systems are used, appropriate modes should be used that meet the objectives of maximum thrust and a smooth decrease in pitch and a descent to an appropriate altitude that allows acceleration to normal and sustainable cruise speed. If manual flight is used, smooth control inputs avoiding abrupt control actions and maximum thrust are necessary. Pilots should be aware that with the increased true airspeed larger changes will occur for the same amount of pitch change as used at lower altitudes. Common errors include incorrect recovery technique. Repeat scenario as necessary time permitting.

The crew begins this lesson in cruise flight with an airplane at an altitude of FL250 or above. The airplane weight should be at or near the maximum for that altitude based upon company or manufacturer's procedures. Ensure crew references applicable cruise charts to determine what the maximum altitude is for the weight and environmental conditions. IOS: Instructor operating system or simulator control panel

1. IOS»POSITION SET»FL 250 or ABOVE

2. IOS»AIRPLANE SET»
   Gross weight: MAX appropriate

3. IOS»ENVIRONMENT SET»
   Weather: As desired
   DAY or NIGHT
   29.92 or STANDARD
   Winds: As desired
   OAT»ISA or as initially required for scenario

Element	Information / check for
Cruise Flight	• Ask crew if they can take the next higher flight level (take note of VNAV max altitude) • Review the use of vertical speed/ other climb modes in climbs and what are the caveats • Ensure crew understands how to determine MAX cruise altitude from Flight Management System (if applicable) as well as supporting documents or manuals (e.g. Performance Manual, QRH, FCOM, etc.) • Ensure crew understands what their buffet margin is for the current altitude and weight combination. • Review different scenarios leading to high altitude stalls and upset conditions. For each scenario, review recovery procedures. • Set or maneuver simulator to situation that is behind the power curve such that a slowdown will occur regardless of thrust setting, with increased ISA
IOS» Take a "snap shot" or save the current phase and position of flight if available to permit repetition of conditions and training	
IOS»Increase OAT as appropriate to simulate flight into warmer conditions	
Airspeed Decay	• Ask crew to disengage auto thrust (only if applicable/required). • Instructor may have remove power from certain aircraft specific systems (e.g. flight computers) to permit aircraft to encounter a stall warning. Autopilot use may be lost. • Instructor may have to set thrust that produces, along with temperature increase, a slow loss in airspeed. • Explain to crew how the aircraft reacts with the Autopilot on and its attempt to maintain altitude. • Explain to crew how the aircraft reacts with the Autopilot on and its attempt to maintain altitude. • Point out airspeed trend and instrument indications (low speed indications/symbology if applicable) • Explain what the aircraft specific threats that will be encountered with various automation situations (split automation, LNAV vs. heading select modes, etc.)

Stall Warning	• Explain to crew what the stall warning system uses to set off warning and in what progression the alerts will take place (visual, aural, shaker, pusher, buffet, etc.). • Make sure crew understands that recovery will begin at first level of warning.
Recovery (Autoflight)	• Crew should command a desirable (down) vertical speed into the auto-flight system. E.g. (-1000ft/min) • Speed should be crew selected to avoid any thrust reduction by auto-flight system • Ensure thrust DOES NOT reduce to idle or below desired setting • Monitor TCAS and SCAN for traffic conflicts • Notify ATC • Crew should determine appropriate new cruising altitude (a descent of at least 1000 feet is recommended to achieve adequate acceleration).
Recovery (Manual)	• Crew should disengage auto-flight systems (if applicable) • Pitch aircraft down smoothly to establish descent, AVOID ABRUPT CONTROL INPUTS, Pilots should be aware that with the increased true airspeed larger changes will occur for the same amount of pitch change as used at lower altitudes • Set thrust to MAX (MAX appropriate to aircraft) • Accelerate to appropriate airspeed • Monitor TCAS and SCAN for traffic conflicts • Notify ATC • Crew should determine appropriate new cruising altitude