Airplane Upset Recovery

High Altitude Operations

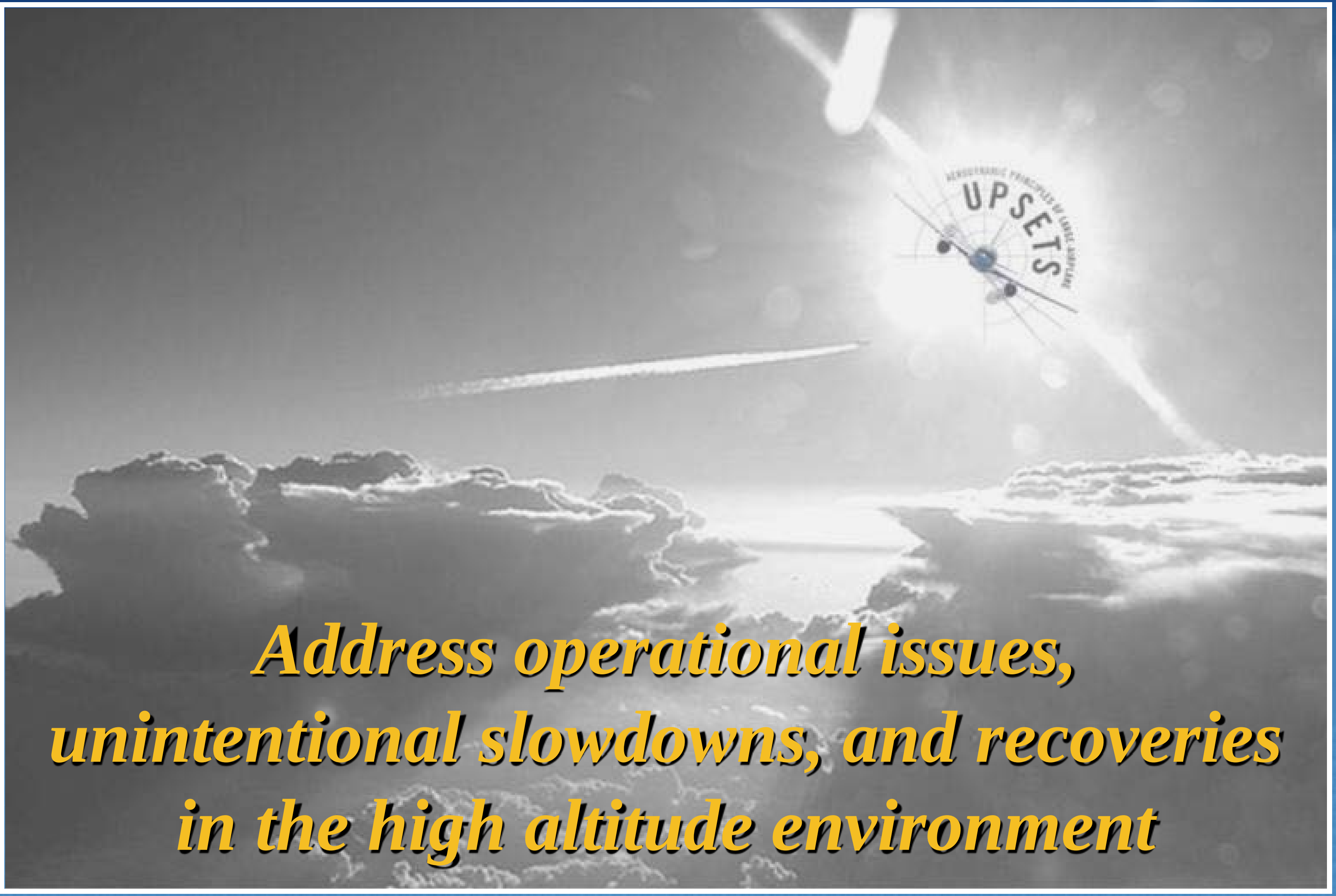
Airplane Upset Recovery Training Aid Team

Rev. 2, November 2008

Introduction

- National Transportation Safety Board (NTSB) tasking following high altitude loss of control accidents and other incidents:
  - Need to address operational issues - unintentional slowdowns and recoveries in the high altitude environment
- Industry working group - formed at the request of FAA
- Team Members:
  - Airlines, safety organizations, manufacturers, regulatory bodies, industry groups, and educational representatives
  - International in scope

Training Aid Purpose



Address operational issues, unintentional slowdowns, and recoveries in the high altitude environment

Goal

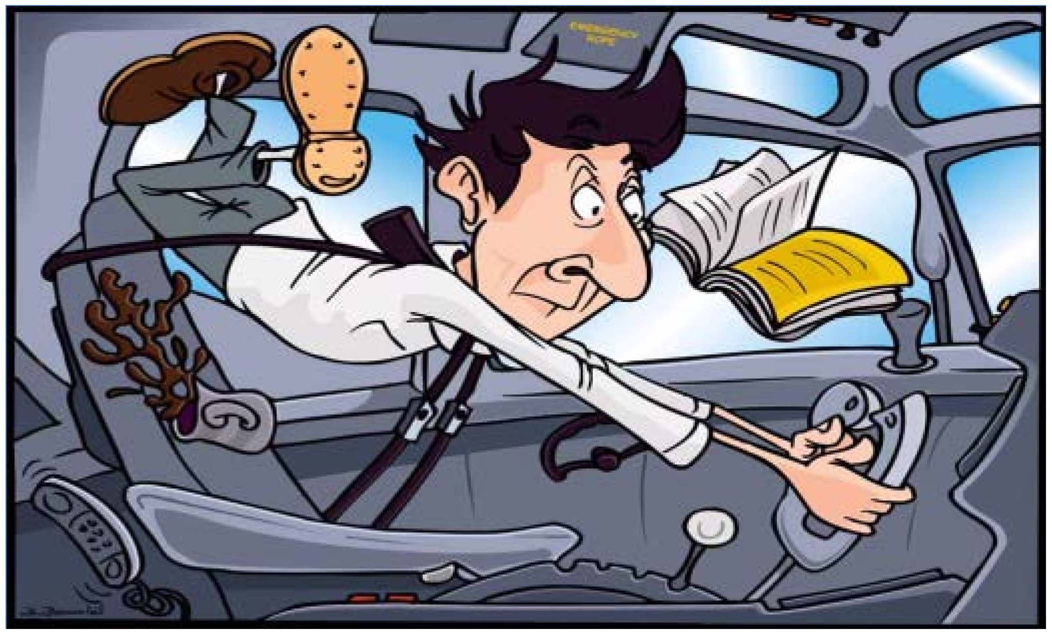
*" Our goal is to educate pilots so they have the **knowledge** and **skill** to adequately operate their airplanes and prevent upsets in a high altitude environment."*

- The Airplane Upset Recovery Training Aid Team

High Altitude Upsets

The *upset - startle factor*

- When ***not*** properly avoided, managed, or flown
  - ***Assures a self-induced upset***



High Altitude Basics

At altitudes where the operational envelope is reduced:

- Be alert!! *No time for complacency*
- Recognize and confirm the situation
- Do not over control…Do not use large control movements – use small control pressures
- Be smooth with pitch and power to correct speed deviations

Presentation

- High Altitude Aerodynamics – Principles
- High Altitude Operations – Flight Techniques
- High Altitude Operations – Additional Considerations
- High Altitude LOFT Training – Overview

Principles


FMC SPD
LNAV
H 057
VNAV PTH
CMD
.80
AERODYNAMIC PRINCIPLES OF LARGE-AIRPLANE
UPSETS
260
220
200
180
.800
GS
455
HDG 057
DME ---
ILS1
0 VS
STD
BARO
269
40 800
119 NM
FMC L

High Altitude Operations

- Knowledge of high altitude aerodynamics
- Pilot Training consists of:
  1. Knowledge and Familiarization
  2. Prevention - Avoidance Awareness
  3. Techniques - High altitude upset recovery

This training aid defines high altitude as - Altitudes above FL250

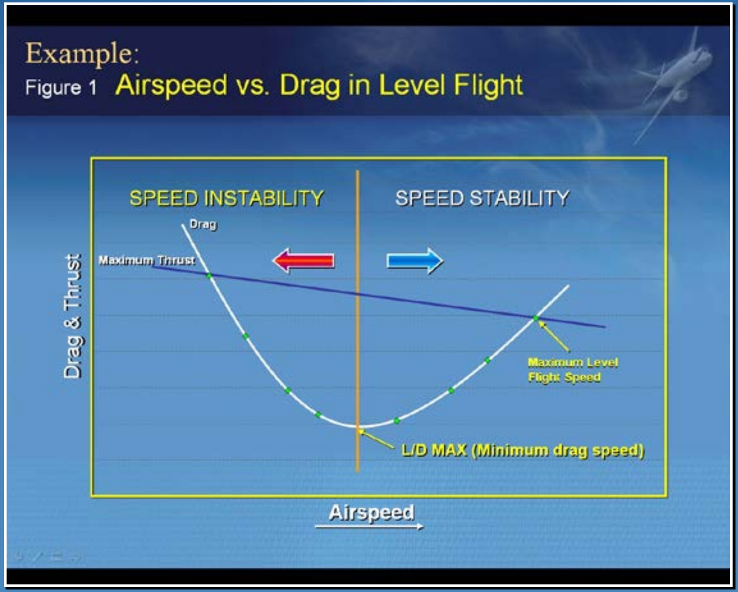
Note: The training aid will focus on the information necessary to prevent and recover from upsets in the high altitude environment

L/D Max

The lowest point on the total drag curve – also known as V_{md} (minimum drag speed)

Pilot Tip

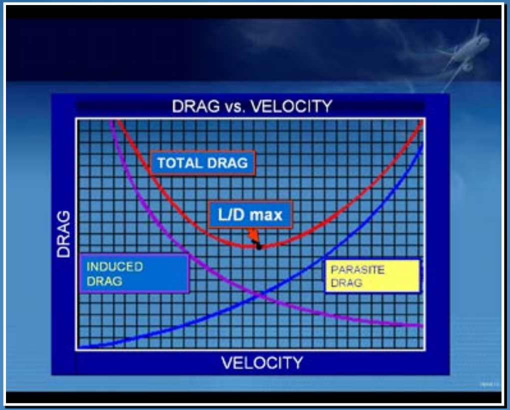
- Airspeed slower than L/D max known as: The "back side of the power-drag curve" or the "region of reverse command"
- Airspeed faster than L/D max is considered normal flight or the "front side of the power-drag curve"



- Normal flight – Speed stable
  Stable Flight - Airspeed disturbance (i.e. turbulence) - Airspeed will return to the original airspeed when the total thrust has not changed

L/D Max (continued)

Pilot Tip
Slower cruising speeds are a concern (approaching L/D max). There will be less time to recognize and respond to speed decay during high altitude cruise.



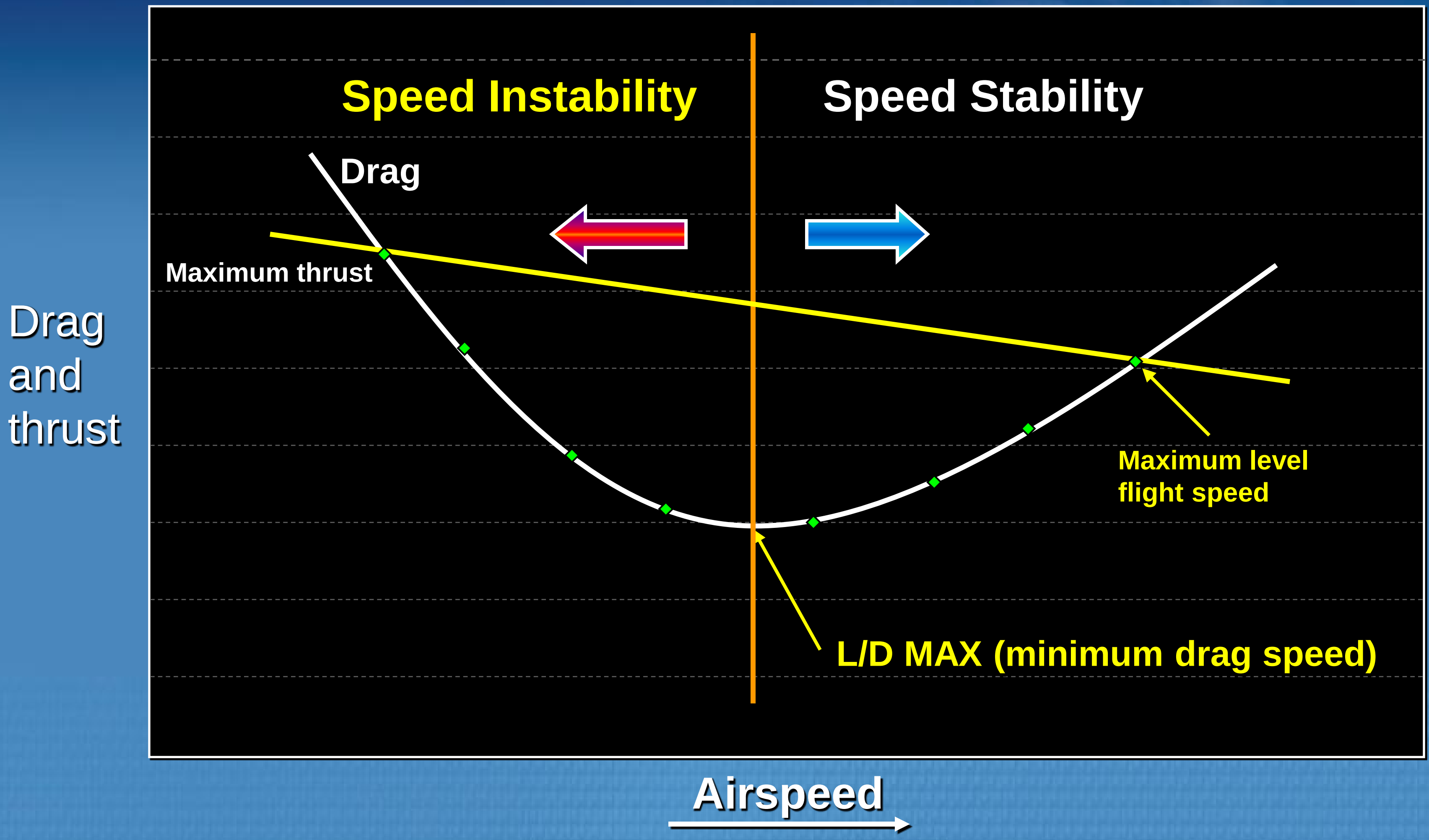
- Slow flight (slower than L/D max) – *Unstable*
- Lower speed – Result: increased drag
- Increased drag – Result: decrease in airspeed

Ultimate uncorrected result – stalled flight condition

Pilot Tip Flight slower than L/D max at high altitudes must be avoided. Proper flight profiles and planning will ensure speeds slower than L/D max are avoided

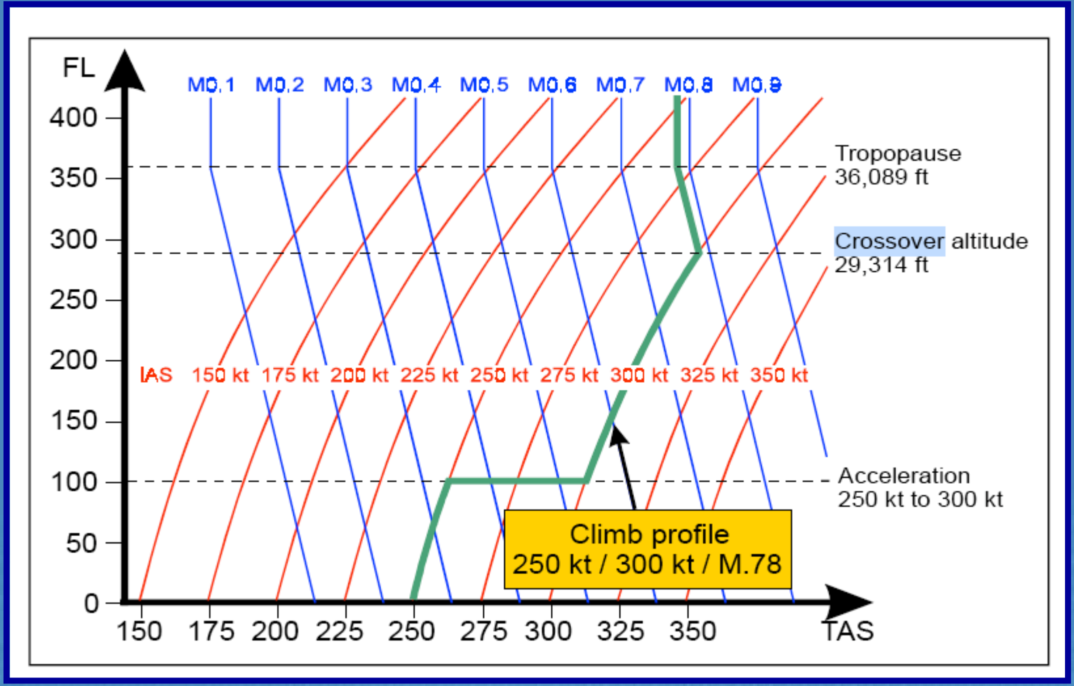
Example

Figure 1 – Airspeed Versus Drag in Level Flight



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



Typical climb profile

Optimum Altitude

- Cruise altitude for minimum cost operating in the ECON mode
- Minimum fuel burn when in the Long-range cruise (LRC) or pilot-selected speed modes
- The Optimum Altitude increases under the following conditions:
  - **ECON mode** – Airplane weight or cost index decreases
  - **LRC** or selected speed modes - Airplane weight or speed decreases
- Temperature - increase in temperature will lower the Optimum Altitude

Pilot Tip

When flying at Optimum Altitude, crews should be aware of temperature to ensure performance capability.

Optimum Climb Speed Deviations

- Optimum climb speed charts and speeds – AFM, FCOM, and FMS
- Increased rates of climb - ensure speed:
  - Not decreased below L/D max

(Incident Data: Primary reason for slow speed events. Improper use of vertical speed modes during climb)

Pilot Tip

Enroute climb speed is automatically computed by FMC:

- Displayed - Climb and progress pages
- Displayed - Command speed when VNAV is engaged

Thrust Limited Condition and Recovery

- Be aware of outside temperature and thrust available
- Most jet transport aircraft are thrust limited, rather than slow speed buffet limited - especially in a turn
- Use Flight Management Systems/reduced bank angle
  - Real-time bank angle protection
  - Routine bank angle limit (10°-15°) for cruise flight

Pilot Tip If a condition or airspeed decay occurs, take immediate action to recover:

- Reduce bank angle
- Increase thrust – select maximum continuous thrust (MCT) if the aircraft is controlling to a lower limit
- Descend

Maximum Altitude

- Highest altitude at which an airplane can be operated - Lowest of:
  - **Maximum certified altitude** (Structural) - Determined during certification and is usually set by the pressurization load limits on the fuselage
  - **Thrust Limited Altitude** (Thrust) – Altitude at which sufficient thrust is available to provide a specific minimum rate of climb

    Note: Depending on the thrust rating of the engines – Thrust Limited altitude may be above or below the maneuver altitude capability
  - **Buffet or Maneuver Limited Altitude** (Aerodynamic) – Altitude at which a specific maneuver margin exists prior to buffet onset

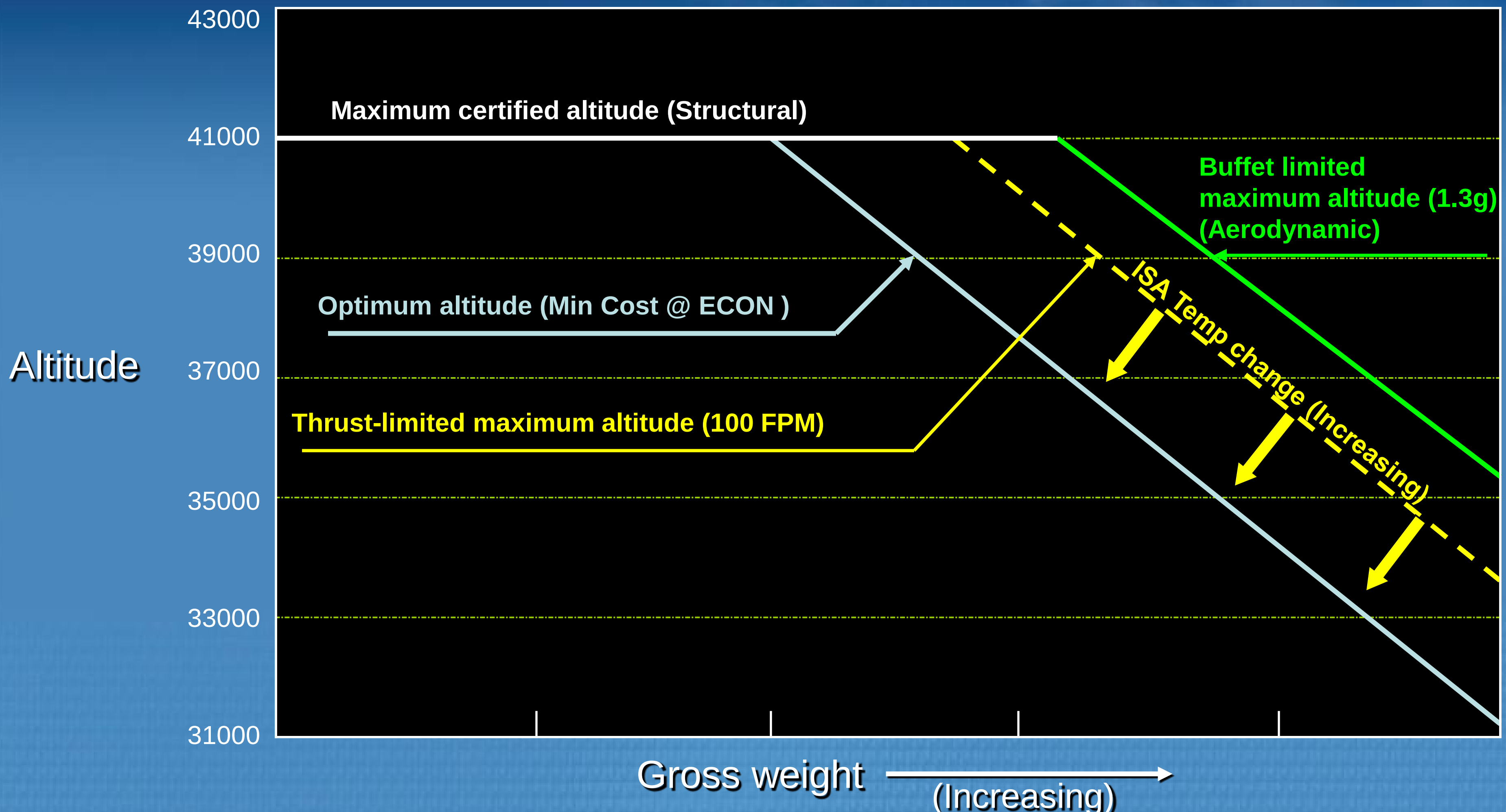
    (FAA operations: 1.2g 33° Bank) (CAA/JAA operations: 1.3g 40° Bank)

Next Slide: Figure 2 – Optimum vs. Maximum Altitude

Figure 2

Typical Optimum vs. Maximum Altitude

Note: As ISA Temp increases – Altitude capability is reduced.



Maneuvering Stability

- Flight Characteristics:
  Constant Airspeed – same control surface movement

High altitude

- Higher pitch rate
- Less aerodynamic damping
- Greater angle of attack

Low altitude

- Lower pitch rate
- More aerodynamic damping
- Less angle of attack

Pilot Tip

High altitude flight normally has adequate maneuver margin at optimum altitude. Maneuver margin decreases significantly approaching maximum altitude.

Pilot Tip Do not over control airplane with large control movements – use small control inputs. Be smooth with pitch and power to correct speed deviations.

Buffet-Limited Maximum Altitude

- Two kinds of buffet in flight:
  1. Low speed buffet
  2. High speed buffet

- As altitude *increases*:
  - Indicated airspeed (IAS) for low speed buffet increases
  - High speed buffet speed decreases

  Result: Margin between high speed and low speed buffet decreases

Pilot Tip

Respect buffet margins - Proper use of buffet boundary charts or maneuver capability charts and FMC calculations allows the crew to determine the maximum altitude.

Buffet-Limited Maximum Altitude

- High altitudes - excess thrust is limited
  - If needed - Select maximum available/continuous thrust at any time

Important: If speed is decaying (airplane getting slow)

– Select Max Available Thrust

Pilot Tip
Select MCT to provide additional thrust. To prevent further airspeed decay into an approach to stall condition a descent may be necessary. Use proper descent techniques.

Pilot Tip Selecting MCT may be insufficient in extreme airspeed decay conditions.

High Altitude Threats

Operating Near Maximum Altitude

Early Turbo-Jet Airplanes – "Coffin corner"

- As the altitude increases - pilot is always trying to maintain a safe airspeed above the stall and a safe airspeed below the Vmo/Mmo
- Difference between the stall and the max speed narrows
  - Coffin corner
- Stall Warning Systems
  - "Stick Shakers", "Pushers", "Audio Alarms"
  - Know your airplane - systems installed and function

Pilot Tip Airplane Buffet is often a first indicator – Stay Alert!!

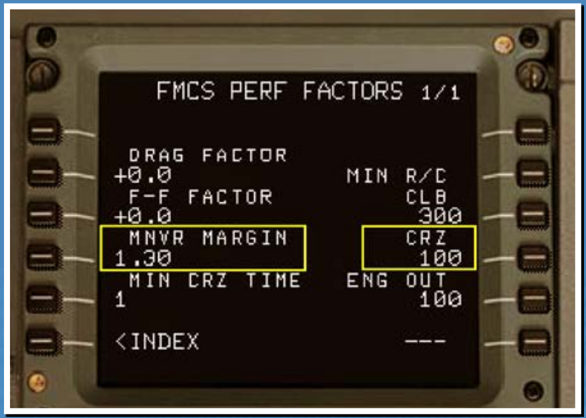
High Altitude Threats

Operating Near Maximum Altitude (continued)

Limits are checked by FMC

Note:

- Available thrust may limit ability to maneuver
- The amber band limits do not provide an indication of sufficient thrust to maintain the current altitude and airspeed

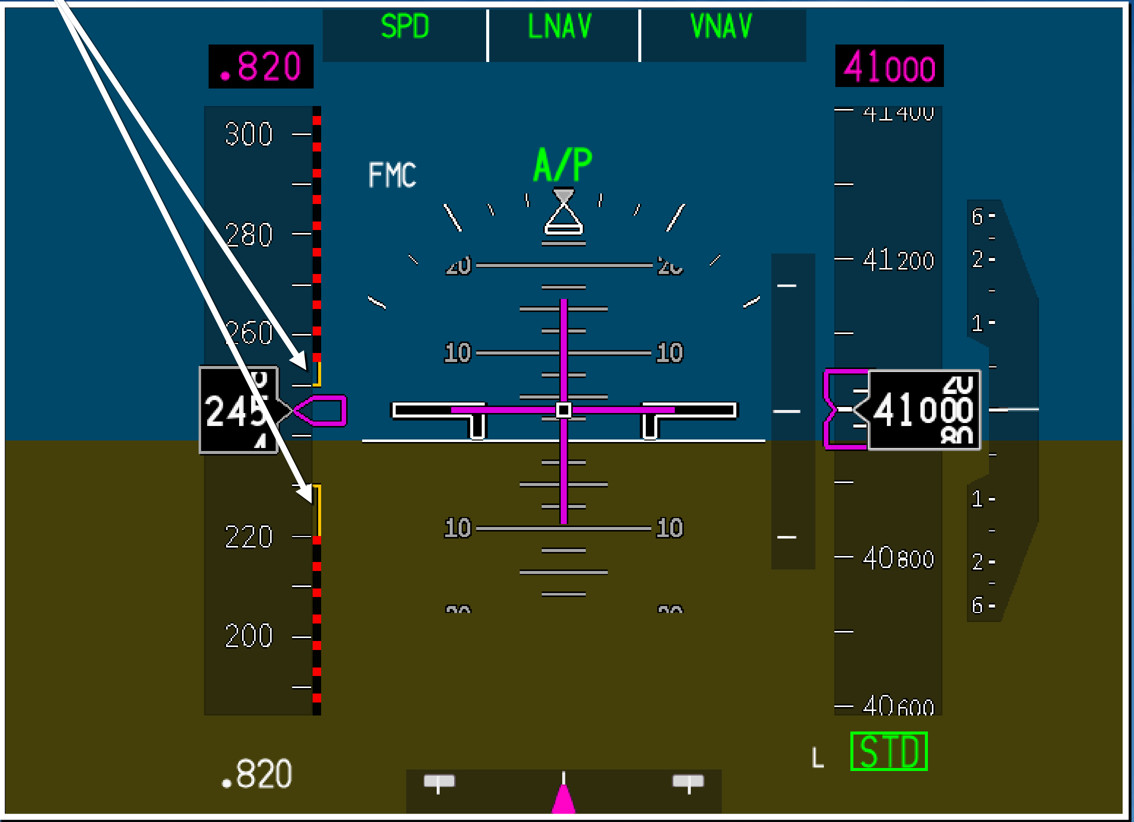


Amber Band

- Displays the range of reduced maneuver capability
- Provides 1.3g/40° of bank angle (default) margin to buffet
- Constant regardless of ambient temperature

Pilot Tip
The amber band does not give any indication of thrust limits.

Amber bands



Pilot Tip The minimum maneuver speed indication does not guarantee the ability to maintain level flight at that speed.

High Altitude Maneuver

Examples: LNAV vs. HDG SEL

15° bank

30° bank

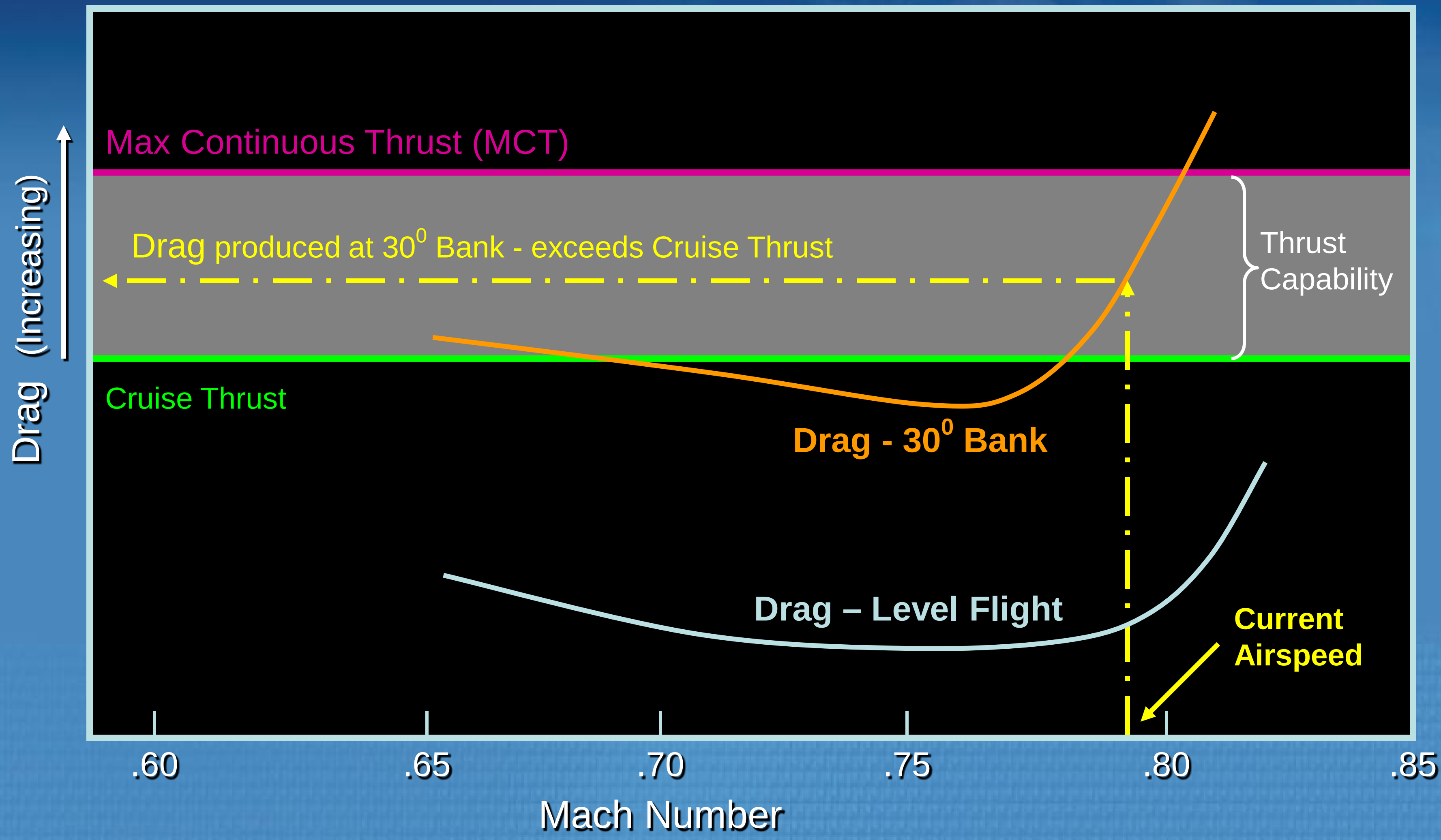
Pilot Tip

For airplanes with real-time bank angle protection, the bank angle limiting function is only available when in LNAV – In HDG SEL bank angle protection is lost.

Pilot Tip Decelerating the airplane to the amber band may create a situation where it is impossible to maintain speed and/or altitude. When speed decreases, the airplane drag may exceed available thrust – especially in a turn.

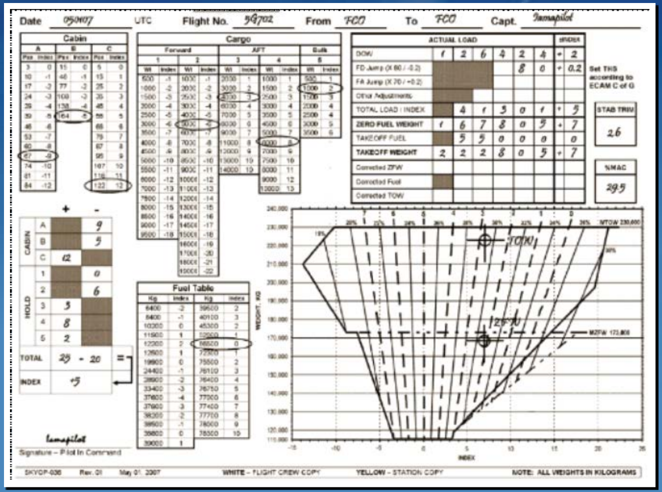
Figure 3

Drag vs. Mach Number



Weight & Balance Effects on Handling Characteristics

- Airplane Handling - Airplanes are typically loaded with an aft CG to improve enroute performance
    1. Aft loading - controls are more sensitive
        – Less longitudinal stability
    2. Loading toward the nose – CG moves forward
        – Longitudinal stability increases

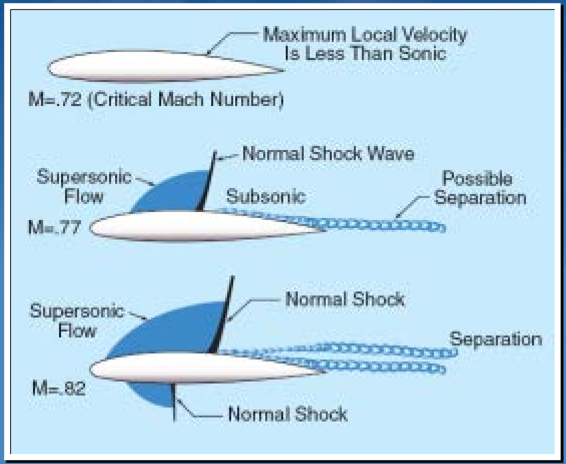


- Weight and Balance limitations must be respected

Pilot Tip: Airplane that is loaded outside the weight and balance envelope will result in aircraft handling that is unpredictable. Stall recovery may be severely impeded. This problem may be magnified at high altitude.

Mach Tuck and Mach Buffet

(Reference: FAA-H-8083-3A Airplane Flying Handbook)



- At speeds above Mmo (some airplanes) – mach tuck will occur
- Critical Mach Number – when airflow over wing reaches Mach 1.0
  - Shock wave will form over the wing
  - Mach buffet will occur
- Mach buffet increases with increased speed
  - Aft movement of the shock wave over the wing's center of pressure
  - Creates "tuck" (nose-down tendency). Because of the changing wing center of lift

Pilot Tip

In modern airplanes this has been largely eliminated.

Stalls

- An airplane wing can be stalled
  - Any airspeed, any altitude, any attitude

Pilot Tip

If the angle of attack is greater than the stall angle, the surface will stall. Attitude has no relationship to the aerodynamic stall. Even if the airplane is in a descent with what appears like ample airspeed - the surface can be stalled.

- Understand the difference between:
  1. "Approach" to stall recovery
  2. Stall recovery

Dramatic difference in recovery technique

Know the Difference

Flight Techniques

Remember the High Altitude Basics

At altitudes where the operational envelope is reduced:

- Be alert!! *No time for complacency*
- Recognize and confirm the situation
- Do not over control…Do not use large control movements – use small control pressures
- Be smooth with pitch and power to correct speed deviations

Altitude Exchange for Energy

Stall Recovery

- Stall Recovery ***is the Priority***
  - Altitude recovery is secondary to stall recovery
- Characteristics of stall:
  - Buffeting, which could be heavy at times
  - A lack of pitch authority
  - A lack of roll control
  - Inability to arrest descent rate
  - These characteristics are usually accompanied by a continuous stall warning

Pilot Tip: Stall recovery is the priority. Only after positive stall recovery, can altitude recovery be initiated. At high altitudes swept wing turbojet airplanes may stall at a reduced angle of attack due to Mach effects.

Altitude Exchange for Energy

Stall Recovery (continued)

Pilot Tip Stall recovery requires that the angle of attack must be reduced below the stalling angle of attack. The elevator is the primary pitch control in all flight conditions… not thrust.

At High Altitude, recovery requires reducing the angle of attack

- The elevator is the primary control to recover from a stalled condition
  - Loss of altitude (regardless of close proximity to the ground)
  - Thrust vector may supplement the recovery - not the primary control
  - Stall angles of attack - drag is very high
  - Thrust available may be marginal, the acceleration could be slow

High Altitude Threats

Operating Near Maximum Altitude

- Airplane Icing
- Clear air turbulence
- Convective turbulence
- Wake turbulence
- Mountain wave
- High Level windshear
- Thunderstorms

Pilot Tip

High altitude weather can cause favorable conditions for upsets. Thorough route analysis is key to avoiding conditions that could lead to an upset.

Slowdown or Stall at High Altitudes

Weather Effects

- Know performance limits of the airplane
- The jet-stream – upper air currents - significant
  - Velocities – can be very high
  - Windshear can cause severe turbulence
  - Windshear – Substantial airspeed decay

Pilot Tip

With upper air currents of decreasing velocity wind shear – the backside of the power curve *may be encountered.*

Pilot Tip: 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. Failure to accelerate out of the backside of the power curve may result in the aircraft stalling.

Icing

Use of Anti-Ice on Performance

- Icing Conditions
  Know anti-ice equipment limitations (flight manual requirements)
  - Temperature limitations
  - SAT (Static Air Temperature)
  - Changing environmental conditions
- Thermal anti-ice – bleed penalty
  Negative effect on the ability to recover from decaying airspeed
  - Airplane may not maintain cruise speed or cruise altitude

Pilot Tip

The bleed penalty for anti-ice results in a reduction of available thrust - increase in specific fuel consumption.

In-Flight Icing Stall Margins

- Ice accumulation increases aircraft weight / drag
- Airplane may exhibit stall onset characteristics before stick shaker activation
- Automation during icing encounters
  – Autopilot and Auto-throttles can mask the effects of airframe icing
  – Autopilot can trim the airplane up to a stall thus masking heavy control forces
  – Pilots have been surprised when the autopilot disconnected just prior to a stall

Pilot Tip In-flight icing - *Serious Hazard* - stalls at much higher speeds and lower angles of attack. If stalled, the airplane can roll / pitch uncontrollably.

In-Flight Icing Stall Margins (continued)

- Adverse Weather Conditions: Stay Alert – Avoidance/Monitor
- Thunderstorm, clear air turbulence, and icing

Avoid potential upset conditions

– Monitor significant weather

– Update weather information

– Important - Trend monitoring of turbulence

– Review turbulence charts

Pilot Tip Adverse weather avoidance is crucial. It is most important that proper airspeed is maintained. Keep an adequate margin above stall, remember that indicated stall speed is increasing and stall alpha is lowering. There are no reliable rules of thumb for icing speeds.

Primary Flight Display Airspeed Indications

- Modern aircraft are equipped with a primary flight display (PFD)
  - Help you maintain a safe airspeed margins
  - Airspeed trending

Important

These displays do not indicate if adequate thrust is available to maintain the current airspeed and altitude

Flight Techniques of Jet Aircraft

Automation During High Altitude Flight

- Automation during cruise
  - Attempts to maintain altitude and airspeed
  - Thrust will increase to selected cruise limit
  - Select MCT (Max Cont Thrust) - to increase available thrust and stop airspeed decay
- Airspeed continues to deteriorate - the only option is to descend

Pilot Tip Pilot must take action before excessive airspeed loss

- The pilot's action - pitch down - increase the airspeed while being in an automation mode that keeps the throttles at maximum thrust
- Autopilot engaged - select a lower altitude - use an appropriate mode to descend
- If the aircraft is not responding quickly enough you must take over manually
- Re-engage autopilot once in a stable descent and the commanded speed has been reestablished

Flight Techniques of Jet Aircraft

Automation During High Altitude Flight (continued)

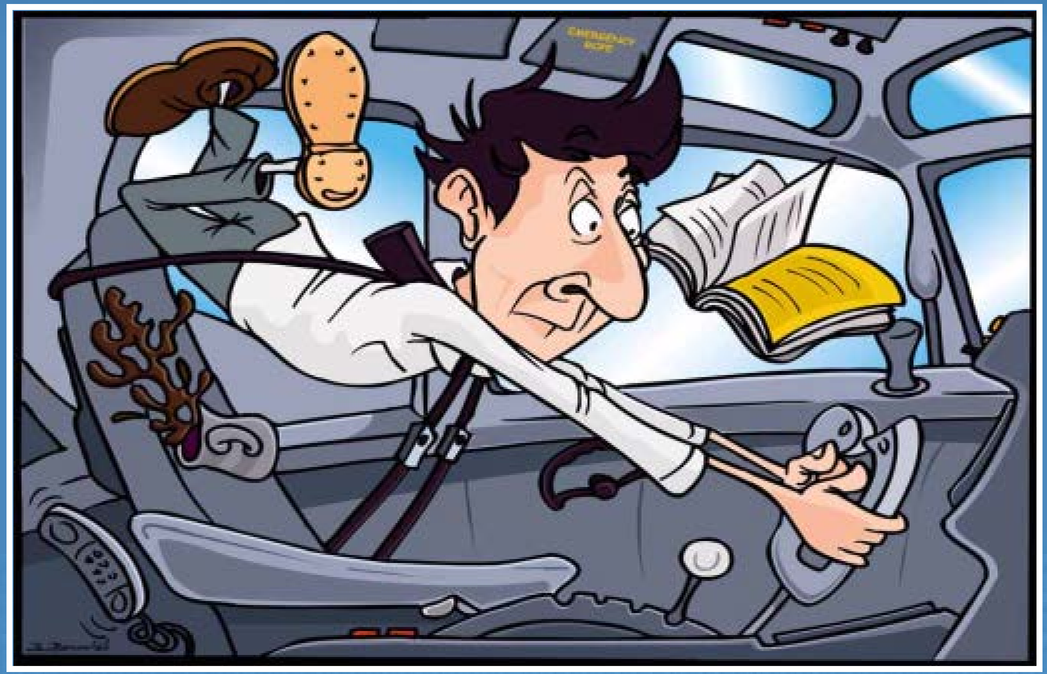
- Vertical Speed Mode (VS) at high altitude - must be clearly understood
  - Energy management, available thrust is reduced at high altitude
    - Manage speed on either elevator or with thrust
    - VS mode, airplane speed controlled by thrust
    - Use of VS has considerable risk during high altitude climb
    - VS mode prioritizes the commanded VS rate
    - Speed can decay, thrust available is less than thrust required
    - Improper use of VS can result in speed loss

Pilot Tip General guideline - VS mode should not be used for climbing at high altitudes

Pilot Tip VS can be used for descent - selecting excessive vertical speeds can result in airspeed increases into an overspeed condition

Human Factors and High Altitude Upsets

- The Startle Factor
  - Dynamic buffeting and large changes in airplane attitude



Human Factors and High Altitude Upsets *(continued)*

- Pilot training – conventional
  - Typical crew training
    - Trained to respond to stall warnings – “Approach to Stall”
    - Usually limited to low altitude recovery
- High altitude - stalls
  - Low speed buffet mistaken for high speed buffet
    - Actual full “Stall Recovery”
    - Higher altitudes

      Available thrust is insufficient

      Reduce the angle of attack

      Trade altitude for airspeed.

- Recognition for recovery is sometimes delayed

Human Factors and High Altitude Upsets *(continued)*

Reasons for delayed recovery

1. Concern for passenger and crew safety following large control movements
2. Previous training emphasized altitude loss
3. Anxiety associated altitude violations and other ATC concerns
4. Less experience with manual flight control at high speed / altitude
5. Lack of understanding - Unaware of the magnitude of altitude loss as it relates to the recovery from the upset condition

High Altitude Operations
Additional Considerations

Multi-Engine Flame Out

Demands Immediate Action

- Prompt recognition of the engine failures – utmost importance
- Immediately accomplishment of the recall items and/or checklist associated with loss of all engines
  - Establish the appropriate airspeed (requires a manual pitch down) to attempt a windmill relight
  - Driftdown will be required to improve windmill starting capability
  - Inflight start envelope is provided to identify proper windmill start parameters

Pilot Tip Regardless of the conditions and status of the airplane - strict adherence to the checklist is essential to maximize the probability of a successful relight.

Pilot Tip Recognition tip – autopilots and A/T may disconnect or indications of electrical problems may exist with a multi-engine flameout.

Corelock

- Turbine engine – abnormal thermal event (e.g flameout at low airspeed)
  Result - the "core" of the engine stops or seizes
- Insufficient airspeed - insufficient airflow through the engine
- Engine – restart capability only when seized engine spools begin to rotate

Pilot Tip After all engine flameouts
  - The first critical consideration is to obtain safe descent speed
  - Determine engine status
  - If engine spools indicate zero - core lock may exist/mechanical engine damage
  - Crews must obtain best L/D_{Max} airspeed instead of accelerating to windmill speed

- Critical: The crew must follow the approved flight manual procedures, maintain sufficient airspeed to maintain core rotation

Rollback

- Turbine engine rollback - uncommanded loss of thrust
  - Reduced N_1 RPM - increase in EGT
  - Many causal factors:
    - Moisture
    - Icing
    - Fuel control issues
    - High angle of attack disrupted airflow
    - Mechanical failure

Pilot Tip If airspeed stagnation occurs, check appropriate thrust level. This is important as well as increasing airspeed in the case of an engine has rollback.

High Altitude Loft Training

High Altitude Loft

Overview

- **Recommendation**
  A high altitude loft is recommended by industry

- **Purpose**
  To familiarize crews with high altitude slowdowns and approach to stall

- **Training Imperatives**
  - Crews should always recover at the first indication of an impending stall
  - Operators may modify this scenario for specific airplane models within their operation

Purpose

Purpose of the High Altitude LOFT training:

1. Train crews to ***recognize*** the high altitude threat due to airplane slowdown and approach to stall
2. Assist crews in how to ***manage*** this threat
3. The exercise is ***not intended*** to train an actual jet upset or full stall
4. Train only to the ***indications of an approach to stall*** before a recovery is initiated

Operators Should consider all the scenario factors that will lead to realistic recovery techniques. Operators should determine the optimum conditions in setting up this scenario.

High Altitude Loft

Training Goal

- Reinforce understanding of high altitude characteristics
- How to determine cruise altitude capability
- Reinforce acceptable climb techniques and – understand the risks associated with various climb techniques – ie. vertical speed (VS)
- Recognize an approach to stall and apply proper recovery techniques
- Discuss automation factors - ie. mode protections, hazards of split automation and inappropriate modes
- Address intuitive and incorrect reactions to stall warning indications
- Develop procedures that are widely accepted to recover from impending high altitude stall conditions with and without auto-flight systems

Summary

Purpose of this training module

- Present an overview of operational issues and how they may contribute to unintentional slowdowns in the high altitude environment
- Discuss aerodynamic principles relating to flight in high altitude environment
- Present pilot tips and techniques for high altitude upset recovery and slowdowns
- Identify factors to aid in early recognition of unintentional slowdowns
- Discuss the training goals for simulator high altitude loft training