Flight at High Altitude in Adverse Conditions – Flight Aspects.

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Overview

- Basic Aerodynamics Recall
  - High/Low Mach Number
  - Maximum Altitude
- Differences in Handling Qualities at Low and High Altitude
  - Flying Qualities
  - Thrust
- Manual Flying in Turbulence & Stress Situations
- Flight in Failure Conditions
  - Classic ‘analogue’ aircraft
  - Integrated aircraft
  - Navigation, Engines, Fly-by-Wire

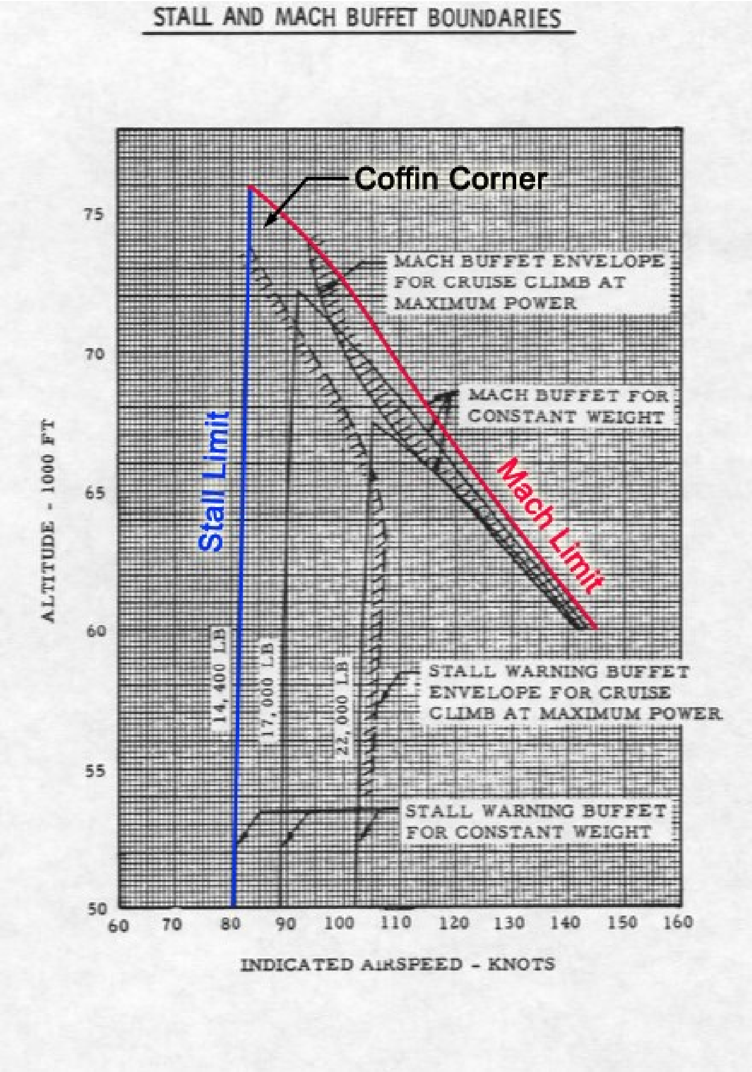
Basic Aerodynamics Recall

- Reduced ρ:
  - Reduced control effectiveness
  - Reduced aerodynamic damping of aircraft motions
- ‘Low’ Mach Number & ‘High’ Angle of Attack
  - Shock stall

Basic Aerodynamics Recall

- High Mach Number & Low Angle of Attack
  - Critical Mach Number & Shockwave formation (mainplane and/or tailplane)
  - Resulting pitching moment changes – Mach tuck
  - Resulting control reversals, pitching/rolling motions.

Basic Aerodynamics Recall



Basic Aerodynamics Recall

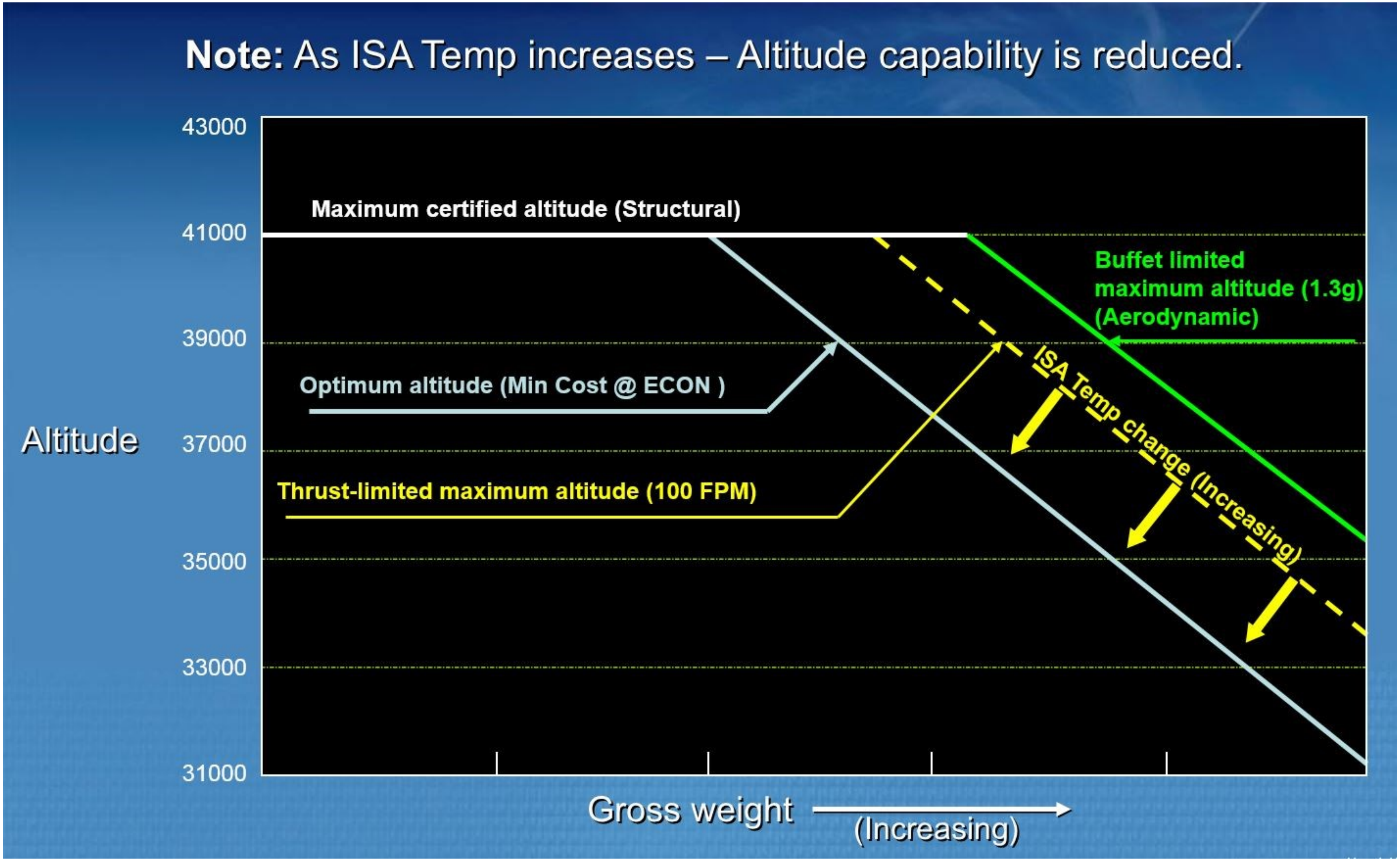
- NB manoeuvre increases angle of attack
  - ‘Coffin corner’ straight and level is higher than the ‘coffin corner’ in manoeuvre
- CS requirements introduce a margin
  - Aircraft should never be at coffin corner or unable to manoeuvre
- Nevertheless, the delta between Max Mach and Min Mach is typically ~20kts at aircraft ceiling ***for a given mass***.

Basic Aerodynamic Recall

Maximum Altitude Factors:

- Structural
  - ΔP limit
- Thrust
  - Minimum climb rate (100 fpm)
- Aerodynamic – buffet/manoeuvre limit
  - Increasing Mass = increasing AoA
  - Therefore ceiling reduces as mass increases.

Basic Aerodynamics Recall



Differences of Handling Characteristics Low & High Altitude

- Low Altitude:
  - Low Mach number, high q
  - High aerodynamic damping
  - Conventional control responses.

Differences of Handling Characteristics Low & High Altitude – Flying Qualities

- High Altitude
  - High TAS, High Mach Number, low q
  - Low aerodynamic damping + high TAS =

  … greatly increased aircraft response to control and to flightpath changes
  - Small changes in flightpath cause rapid diversion from desired parameters
  - Small control inputs produce greater aircraft responses relative to low altitude
  - **Very easy for pilot to overcontrol**.

Differences of Handling Characteristics Low & High Altitude – Flying Qualities

- High Altitude
  - Undesirable aircraft oscillations (e.g. Dutch Roll, Short Period Pitch Oscillations) take longer to damp out and may be exacerbated if pilot attempts to intervene
  - Greatly reduced margin to M_{MO} and M_{Stall}
    - aircraft limits or loss of control (stall) more easily reached
    - aircraft passes much more rapidly from front-side to back-side of drag curve.

Differences of Handling Characteristics Low & High Altitude - Thrust

- Increased altitude has similar effects on engine to airframe
  - Results in restricted operating regime – translates to pilot as a reduced rpm range but thrust lever range is unchanged
  - Thus thrust lever sensitivity is increased and…
  - Significant deadband between the thrust lever idle stop and engine idle rpm.

Differences of Handling Characteristics Low & High Altitude - Thrust

- Engine stall/surge margins reduced…
  - Engine response to acceleration and deceleration reduced - sluggish
- Engine thrust greatly reduced at altitude
  - potentially impossible to accelerate out of second regime without descending
- Combination of these effects can lead to overcontrolling in thrust
  - increasing risk of stall or M_{MO} excursion.

Manual Flying at High Altitude

- What is Manual Flying?
- May be…
  - Manual flightpath control with automatic throttle
  - Automatic pilot with manual throttle control
  - Manual flightpath and throttle.

Manual Flying at High Altitude

- Manual flying at high altitude is usually due to loss of autopilot
- Pilots do not typically fly manually at high altitude because:
  - Fatigue is increased
  - Regulation – RVSM
  - Airline SOP (Passenger comfort?)
  - It is more difficult
  - There is a recognised increased risk of loss of control or envelope excursion.

Manual Flying in Turbulence

- Turbulence causes divergences from desired parameters
  - Pilot makes control input to correct divergences
  - Risk of overcontrolling
- If turbulence is severe enough, may lead to minor envelope excursions due to small margins
- If pilot overreacts to excursions
  - increased risk of further excursions, stall or major exceedance of M_{MO}.

Manual Flying in Turbulence

- Risk of coupling between pilot and flight control inceptors
  - increased with controls with small ranges of movement such as sidesticks
- Thrust effects – overcontrol in thrust.

Manual Flying in Stress Situations 1

- Manual flying under stress is a Human Factors issue which is exactly like driving very fast while arguing with your wife:

Manual Flying in Stress Situations

- Stressed pilot makes jerky control inputs and tends to over-control
- Stressful situation leads to reduction in mental capacity and reduced ability to multi-task
- Stress induces focus on single flight parameters (scan break-down)
- Pilot may be distracted longer-term from flying task
  - Distraction from flying task leads to flightpath excursions being noticed late and tendency to make large inputs to correct.

Manual Flying in Stress Situations

- Startle effect due to in-flight failure greatly increases risk of loss of control
- Time to envelope excursion is very low due to restricted flight envelope – increased pressure

Manual Flying in Stress Situations

Reaction vs Startle

- Startle is not Reaction time and vice versa
- Reaction implies situational awareness
- Certification can account for reaction times…
- …but cannot account for Startle effect.

Flight in Failure Conditions

Classic Analogue cockpit with traditional flight control system

- Easy for pilot to understand Pitot-static system
- Few systems dependant on Pitot-static information
- Angle-of-Attack systems rarely fitted (stick-pushers)

Flight in Failure Conditions

- Flight control system had simple dependencies on sensors (e.g. Q-pot)
- Flight control system had simple mechanical gain changes (e.g. single gearing change with altitude)
- Navigation systems had few dependencies on aircraft sensors (VOR/DME, INS)
- End Result:
  - sensor failures relatively simple to diagnose for pilots
  - Failure procedures relatively simple for manufacturers to design

Flight in Failure Conditions

- Modern aircraft have introduced:
  - Integrated cockpit instruments
  - Flight Management Systems as primary means of navigation
  - FADEC-controlled engines
  - Fly-by-wire flight control systems

Flight in Failure Conditions

Integrated Cockpit Instruments

- Colour, computer-generated information
  - Compelling, even if displayed information is incoherent or incorrect
- Automatic switching logics in failure cases may make diagnosis difficult
- Parameters may be blended from several sources…

Flight in Failure Conditions

- Aircraft limitations are now displayed dynamically on displays (e.g. stall speed, maximum speeds)
  - may be lost
  - May be incorrectly displayed
  - = reduced pilot awareness of envelope restrictions or inducing inappropriate pilot reactions…

Flight in Failure Conditions

- PFD layout is optimised for flightpath monitoring rather than flightpath control
  - e.g. tape displays for airspeed and altitude reduce rate awareness.

Flight in Failure Conditions

FMS as Primary Navigation Means

- Crews depend on FMS for navigation
  - Pilots used to ‘build’ SA from raw
  - Now accustomed to high accuracy with zero workload…

Flight in Failure Conditions

FMS as Primary Navigation Means

- Loss of aircraft sensors may lead to degraded modes of FMS operation
  - Increased crew workload or confusion
- Loss of aircraft electrical systems may lead to loss of FMS
  - Reversion to needles – skill fade?

Flight in Failure Conditions

FADEC-Controlled Engines

- Loss of aircraft sensors may lead to:
  - Engines operating in degraded modes
  - Reduction in engine performance
  - Reduction in engine protections
  - Erroneous engine operations (thrust-pulsing, reduction to idle, increase to TOGA)
- Increased crew workload...

Flight in Failure Conditions

- Loss of autothrottle/autothrust function
- Loss of thrust protection systems
- End Result: increased risk of envelope excursion or loss of control

Flight in Failure Conditions

Fly-by-Wire Control Systems

- Completely dependant on aircraft sensors for correct operation
- Loss of sensors = reduction in FBW functionality and degraded modes
- Degraded modes:
  - Loss of protections for high or low speed/Mach/AoA
  - Degradation in handling qualities (auto-trim, thrust/config compensations, yaw-damping, roll-damping, artificial stabilities in all 3 axes, etc)…

Flight in Failure Conditions

- Failed (failed but not set invalid) sensors considerably more complicated
  - Control law gains set to incorrect values
  - Inappropriate triggering of protections
  - Unalerted loss of protections
  - Flight Phase individual laws or adaptations may be lost or activated inappropriately (e.g. changes to flare handling qualities, abrupt changes between flight phase modes)
- Impossible to create specific procedures.

Flight in Failure Conditions

- Pilots get used to an aircraft's 'everyday' handling qualities
- Pilots quickly become dependant on both enhanced handling qualities and protections…

Flight in Failure Conditions

- End Result in event of degraded FBW:
  - Increased potential for mishandling leading to loss of control or envelope excursion
  - Greatly increased pilot workload and stress (unexpected inability to fly properly)
  - Increased risk of loss-of-control or envelope excursion due to conditioned expectation that protections are always present.

Discussion Points

- Pilots must refresh their own professional knowledge of aerodynamics
- Increased training and exposure to manual flying at high altitude
- Incorporation of ‘surprise’ elements to recurrent simulator training to expose pilots to startle effect
- Ensure that simulators are representative of the real aircraft for flight at high altitude and high/low Mach outside operational envelope

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Discussion/Questions?