Envelope Expansion Dives: Refining Build-up Techniques

Aaron Tobias (M)
Maurice “Moe” Girard (AF)
Cessna Aircraft Company
Wichita, KS

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Overview

- Background
- Phase 1: Atmosphere Monitoring
- Phase 2: Atmosphere Management
- Phase 3: Trajectory Planning

- Lessons Learned
- Conclusions
- Questions
- Mechanical-Reversible Flight Controls
- Typical $M_D$'s of Mach 0.80 to 0.9X
- High Elevator Forces
  - Slow aircraft response (vs fighters)
- Significant Dive Angles Required
Safety Systems
Test Build Up

Vmo/Mmo

Vd/Md

Vdf/Mdf

Test Points

Structural Design Dive Boundary (M₀)

Operating Boundary (Mₘ₀)

Operating Knee (Vₘ₀/Mₘ₀)

Design Dive Knee (Vₚ/Mₚ)

Target Flight Test Boundary

Pressure Altitude (ft)

KCAS
Accident-Free History

...must be a “Safe” Operation, right?

WRONG!!

The Perfect Setup for a:

“12-Step Program”
Step 1: Admit you have a problem

- Certification By Over-speed (“TLAR” Approach)
  
  ‘That Looks About Right’

+0.024 M

+0.010 M (~3 kts) (tolerance)

Target Mach

Dive Progression
Nose rising + Mach slowing = Recovered?

Target Mach

Pitch Recovery Initiated

Dive Progression

11:26:00 - 11:26:30
The Culprit

- Steady Inversion
- Target Mach
- Sharp Inversion
- Stable Layer
- Pitch Recovery Initiated
- Dive Progression
Step 2: Characterize the Problem

- Phase 1: Atmosphere Monitoring
- Lesson Learned: “Watch out for inversions”
- Observed temperature in climbs
  - But no plan to manage
Step 3: Over-Confidence & Complacency Sets In

- Next 2 Dive Programs
  - No inversions encountered

- “Lessons Learned” not reinforced
Step 4: Realize “Lesson Learned” is Incomplete

- Atmospheric Effects Compounded
- Drag Profile Changes (shakers removed)
- Standard Build-Up Sequence Dismissed
  - Straight to $M_D$ (Low-Mid-High)
- First point targeted $M_D$ at FL 320

- Target Mach

- Very Stable Air

- Dive Progression
- Next point targeted $M_D$ at FL 420

+0.043 M

2 sec

Target Mach

Dive Progression
Recovery initiated on point.
- Another inversion effect? No!

Dive Progression

Target Mach

Inversion above target altitude

Stable Lapse

+0.043 M

2 sec
- Windshear...Windshear!

Dive Progression

Increasing Tailwind

Target Mach

Increasing Headwind

+0.043 M

20 kt TW

2 sec

10 kt HW
Step 5: Go Visit an Old Friend... Relapse!

- “No build-up required”

- Abort/recovery procedures/technique

- Over-speed effects/hazards
Inversion noted in cockpit at FL360, and another called by TM at FL390.

Inversion @ ~FL360

Inversion @ ~FL390
1st point completed in very good air with minimal overshoot.

Target Mach

Dive Progression
Next Dive--Only a “little” overshoot?

Target Mach

Dive Progression

+0.023 M

CALT (FEET)
Increasing Tailwind

Dive Progression

Target Mach

Pitch Recovery Initiated

Decreasing Tailwind 3 kt/sec

5 kt TW

40 kt TW

2 sec
Only a “little” overshoot?
Load Factor Effect

Target Mach

Dive Progression

+0.023 M

1.0 G
Aileron Activity

**Target Mach**

**Dive Progression**

- ALFOR1 (4) - LBS
- LT
- ALPSR (3) - DEG
- TED
- TEU
- MACH (2) - MACH
- +0.023 M

- NZ (1) - G
- DN
- 1.8
- 1.0 G
Step 6: Admit you **still** have a problem
Step 7: Record & Communicate Lessons Learned

- Detailed briefing at Quarterly safety meeting.
- Procedures distributed (FT WIKI/SOPs)
Step 8: Phase 2—Atmosphere Management

- Sounding Data: http://rucsoundings.noaa.gov/
- Dedicated TM personnel to monitor/characterize
- Undershoot targets above inversions/shear layers
Flight Test Simplified
Atmospheric Sounding Data
Temperature instability between FL435-440
~10 kt wind shear in same altitude range
Undershoot Targets…but “How Much?”

Transition time vs descent rate

- **Rules-of-Thumb**
  (derived from experience on recent Citation models)
  - For every 5 kts shear, reduce target Mach above shear layer by:
    - 0.010 M (if transitioning shear layer in < 3 sec)
    - 0.005 M (~ 5 sec)
    - 0 (> 10 sec)
  - For every 2 °C “Net” inversion, reduce target Mach above inversion layer by:
    - 0.005 M (if transitioning inversion in < 1 sec)
    - 0.003 M (3 sec)
    - 0 (> 5 sec)
Undershoot Targets...Example

- 300 ft/sec (18,000 ft/min), with NET 6°C inversion
  (expect normal lapse rate of 2°C increase, but measured atmosphere shows 4°C decrease):
  - 300 ft (< 1 sec) ~ 0.015 M
  - 900 ft (3 sec) ~ 0.009 M
  - 1500 ft (5 sec) ~ 0.000 M

- Application on recent program, resulted in < 0.005M overshoots (~1.5 KIAS)
+0.002 M

Target Mach Before Inversion/Shear

Atmospheric Mach Rise

Adjust Pitch as required < FL435 (TLAR)

Dive Progression
Step 9: Phase 3—Trajectory Planning

- HQ Simulator – Drag model to develop techniques
  - Pitch targets
  - Initial altitude
  - Recovery initiation altitude
  - Minimum altitude after recovery completed.

- TM Adjustments of predicted trajectories after each dive
- Load factor build-up to predict structural dynamic effects.
CAS vs. Altitude (ISA)—HQ Sim Profiles

Solid line dives from FL450, recoveries initiated at FL300

Dashed line dives from FL370, recoveries initiated at FL290

CAS (knots)

Altitude (ft)

24° 25° 27° 29° 30° 34° 35°

V_D/M_D
Step 10: Combined Approach

- **Pitch Targets Analytically Defined**
  - Atmospheric Management Data
  - Trajectory Planning
  - Build-up on each flight
  - Continuously update Atmosphere and Trajectory data on each dive and adjust as required.

- **Mach Acceleration Parameter**
  - Mach “trend vector”
Step 11: Showtime!

Net 8°C Inversion between FL400-420
Step 11: Showtime!

~10 kt wind shear at top of critical altitude band
+/-5 kt wind shear

5° Inversion
Target Mach

Target Mach Before Inversion/Shear

Atmospheric Mach Rise

Pitch Target

Dive Progression
Envelope Clearance in 10 dives

Altitude (ft)

Airspeed (KCAS)
Step 12: Write an SETP Presentation!

“Go slow and get there fast.”
Lessons Learned

- Some tests are always High Risk, even if we’ve “been there” many times, external variables may be different
  - Safety systems required
  - Always use conservative build-up plan to evaluate all variables

- Inversion/shear effects on constant Mach dives are significant
  - Utilize dedicated staff to manage atmospheric effects.

- Dive profile development using simulator models is beneficial
  - Refine predicted profiles after EVERY point.

- Evaluate load factor effects during buildup for recovery considerations

- PNF guard throttles & (speed brakes) during dives
Conclusions

- Combined approach requires:
  - More preflight planning/analysis
  - More people to support flights with careful task assignments on and between conditions.
  - Continuous adjustments for actual conditions

- But can be:
  - More consistent
  - Faster
  - Safer