Cessna
A Textron Company

Envelope Expansion Dives: Refining Build-up Techniques

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

SETP Central Symposium, June 2012

Overview

- Background
- Phase 1: Atmosphere Monitoring
- Phase 2: Atmosphere Management
- Phase 3: Trajectory Planning
- Lessons Learned
- Conclusions
- Questions

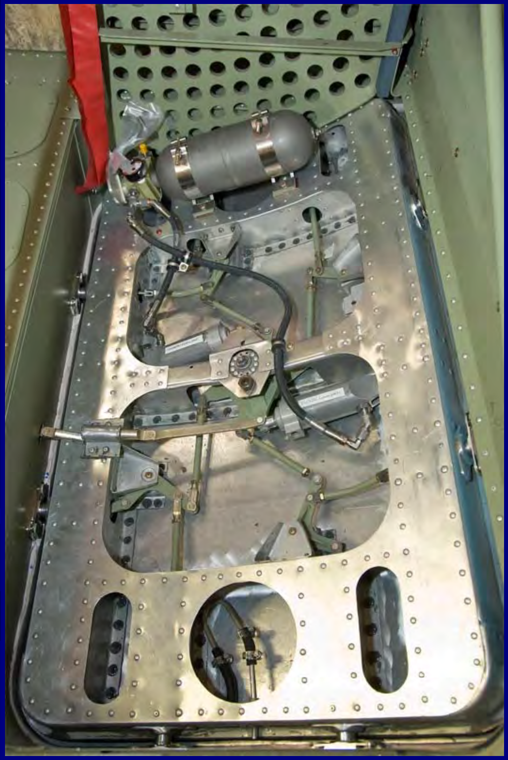

Cessna
A Textron Company

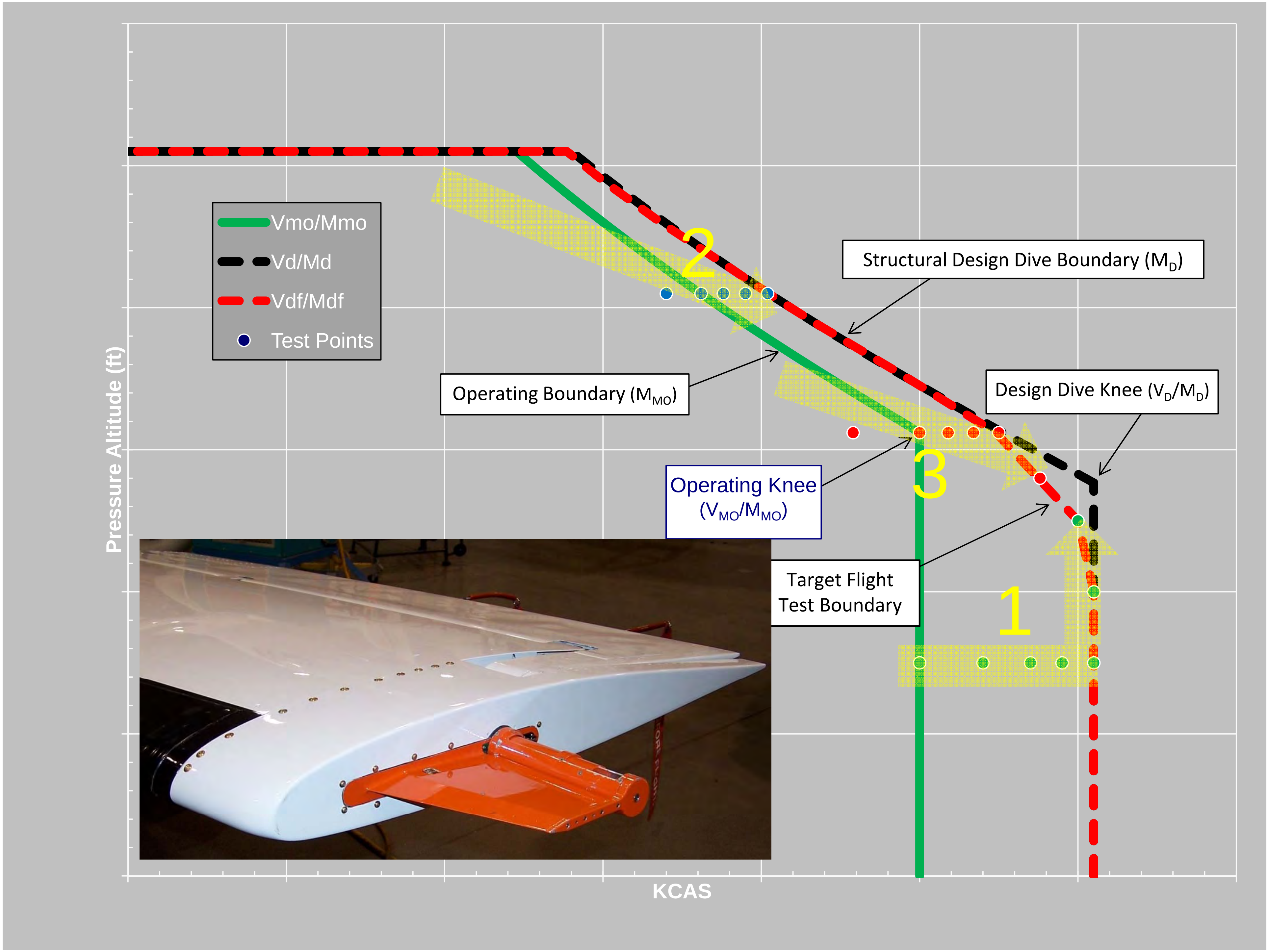

N2W


N750CT
N750CX
Citation X

- 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





Vmo/Mmo
Vd/Md
Vdf/Mdf
Test Points
Structural Design Dive Boundary (M_D)
Operating Boundary (M_{MO})
Design Dive Knee (V_D/M_D)
Operating Knee
(V_{MO}/M_{MO})
Target Flight
Test Boundary
1
2
3
Pressure Altitude (ft)
KCAS

Accident-Free History

…must be a "Safe" Operation, *right?*

WRONG!!

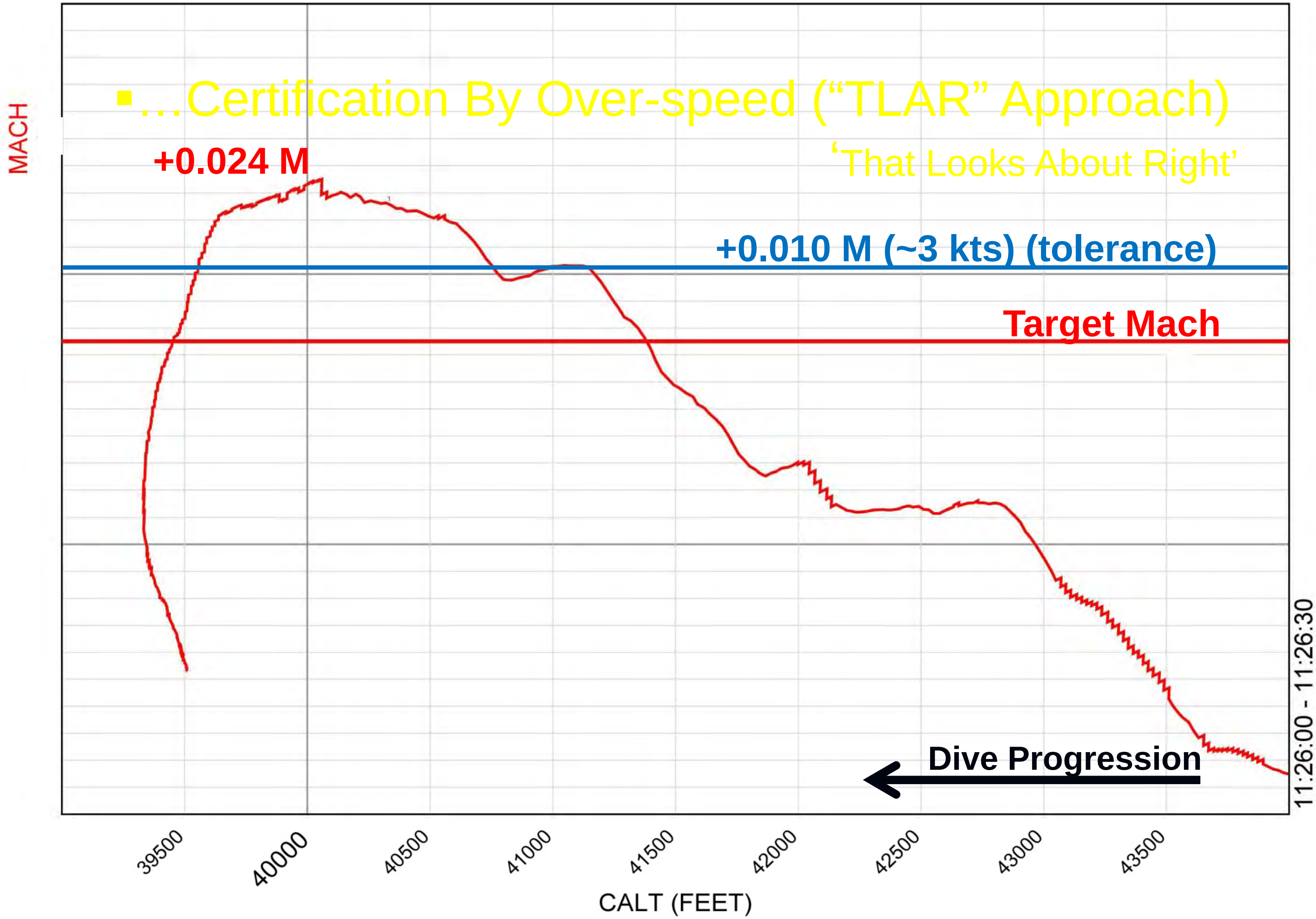
The Perfect Setup for a:

"12-Step Program"

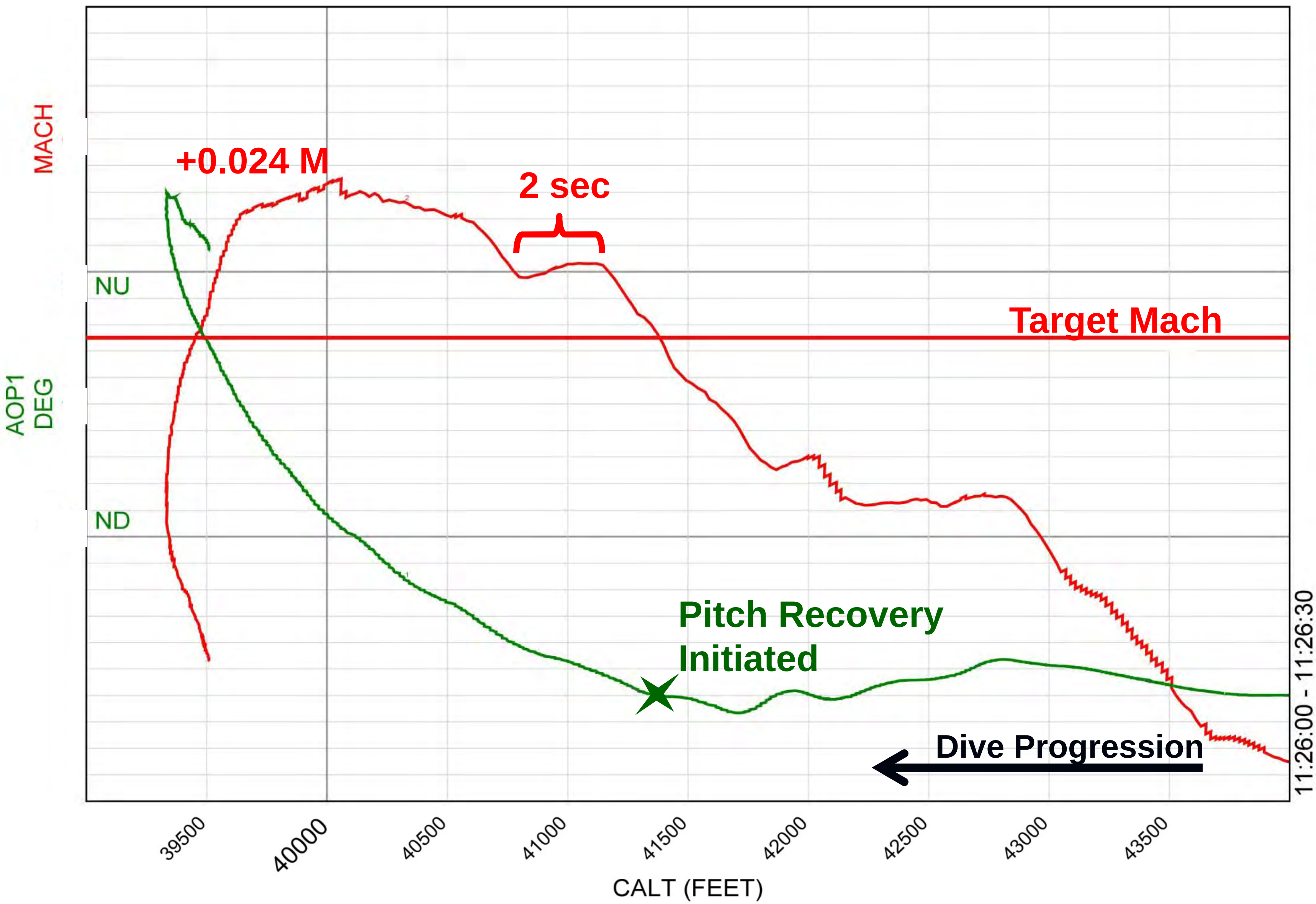
Step 1: Admit you have a problem

- …Certification By Over-speed ("TLAR" Approach)

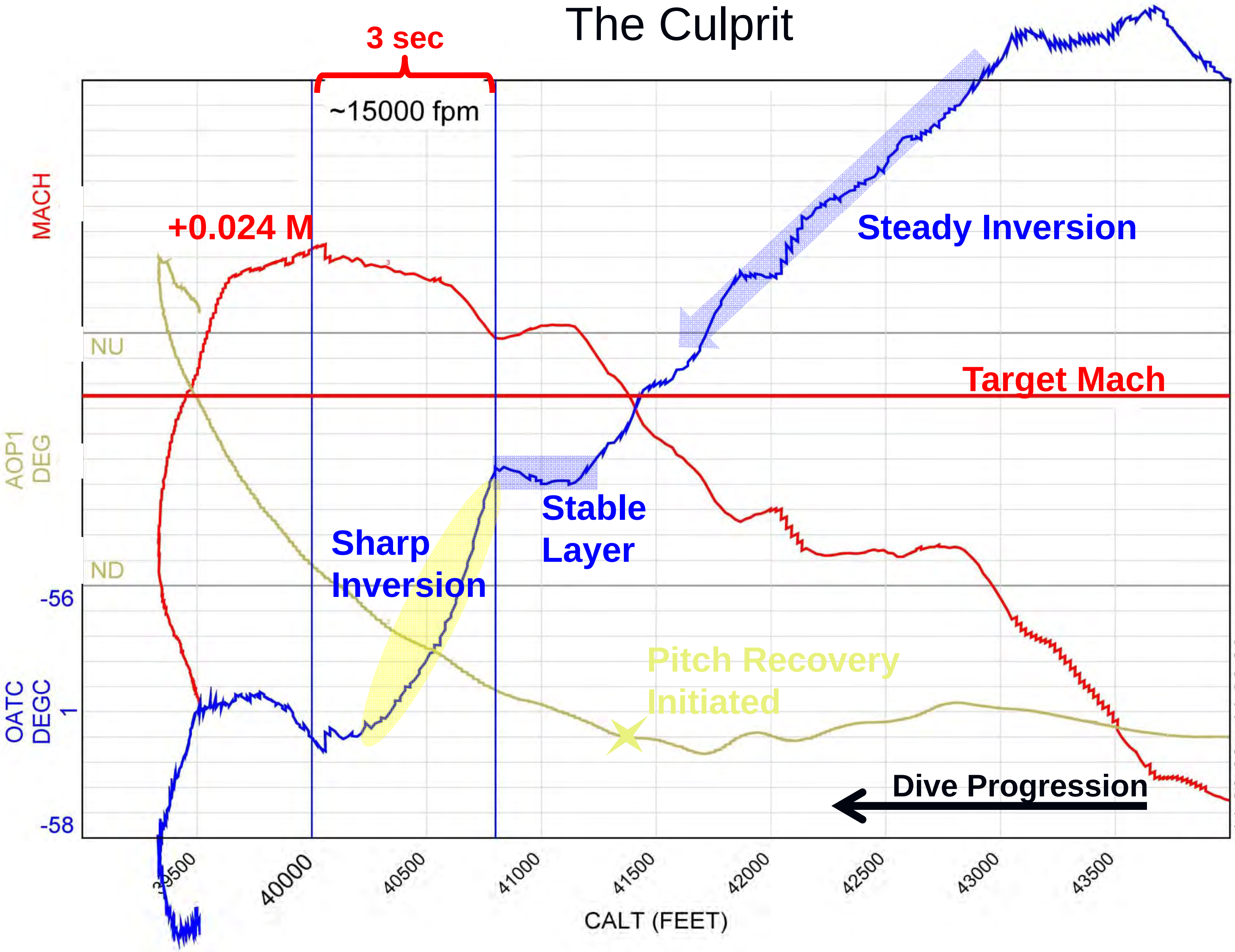
'That Looks About Right'



Nose rising + Mach slowing = Recovered?



The Culprit



3 sec
~15000 fpm
+0.024 M
MACH
NU
AOP1 DEG
ND
-56
OATC DEGC
-58
Target Mach
Steady Inversion
Sharp Inversion
Stable Layer
Pitch Recovery Initiated
Dive Progression
39500
40000
40500
41000
41500
42000
42500
43000
43500
CALT (FEET)
11:26:00 - 11:26:30

Step 2: Characterize the Problem

- Phase 1: Atmosphere Monitoring
- Lesson Learned: “Watch out for inversions”
- Observed temperature in climbs
    - But no plan to manage

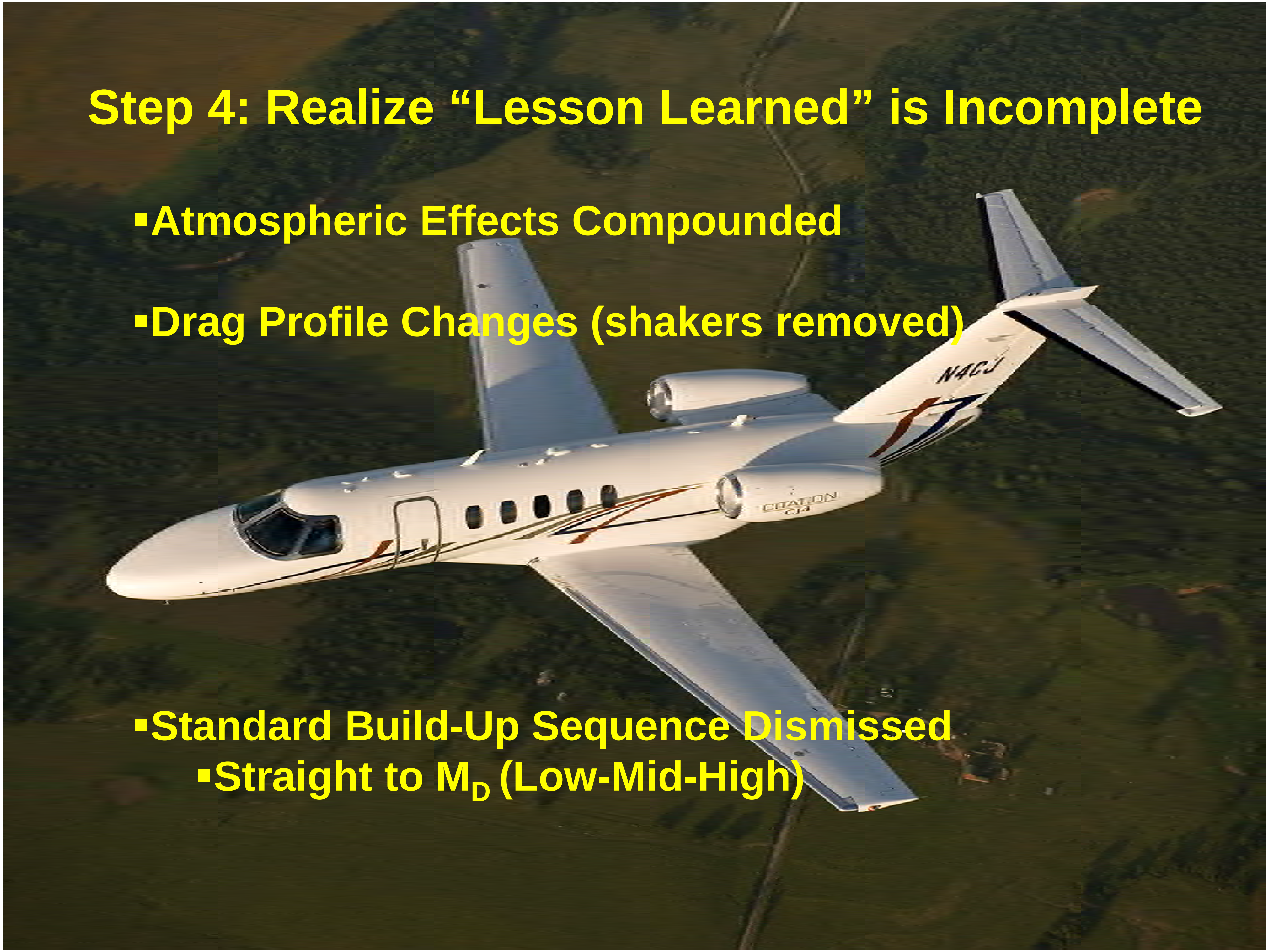
Step 3: Over-Confidence & Complacency Sets In

- Next 2 Dive Programs
  - No inversions encountered

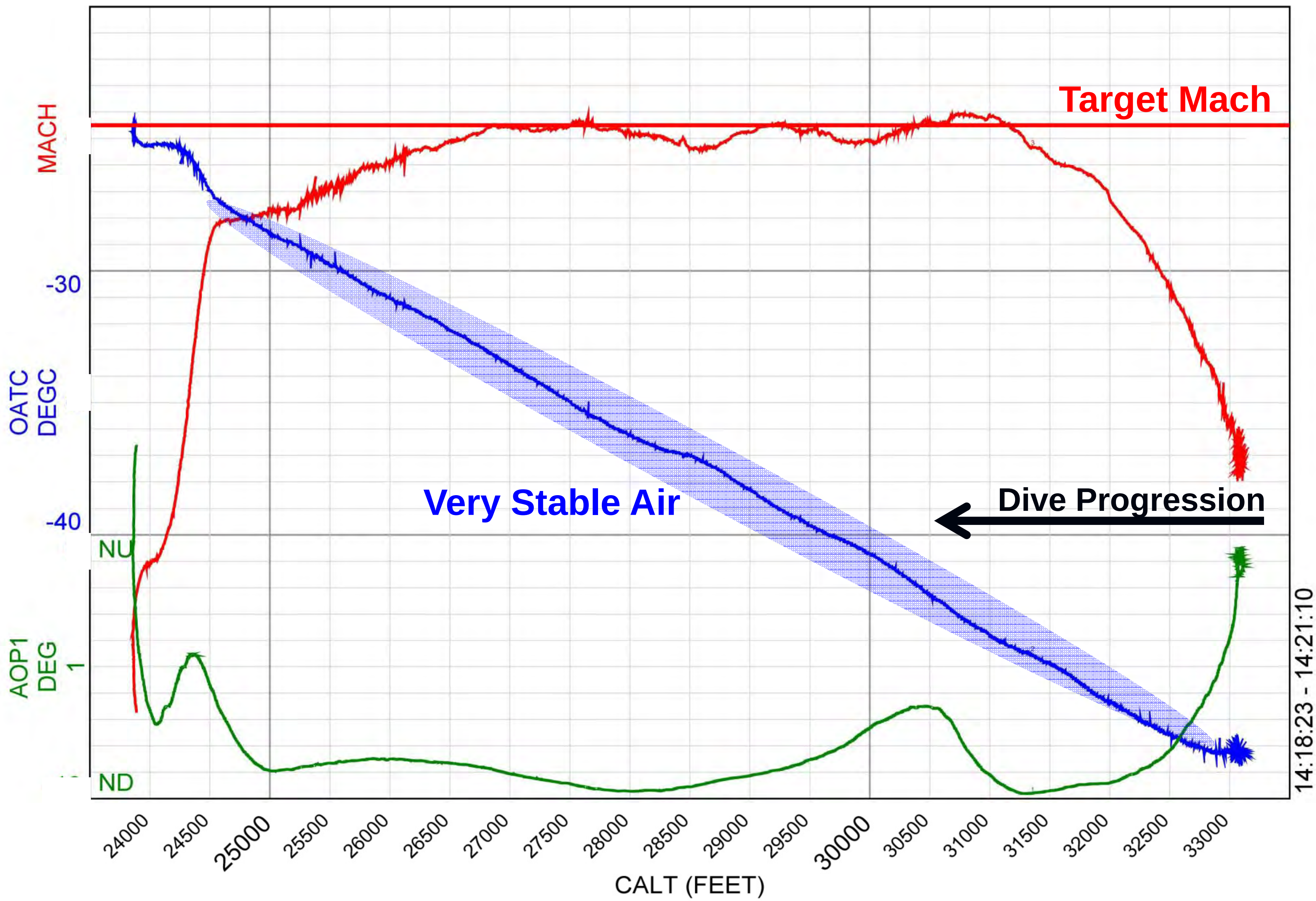
- "Lessons Learned" not reinforced

Step 4: Realize "Lesson Learned" is Incomplete

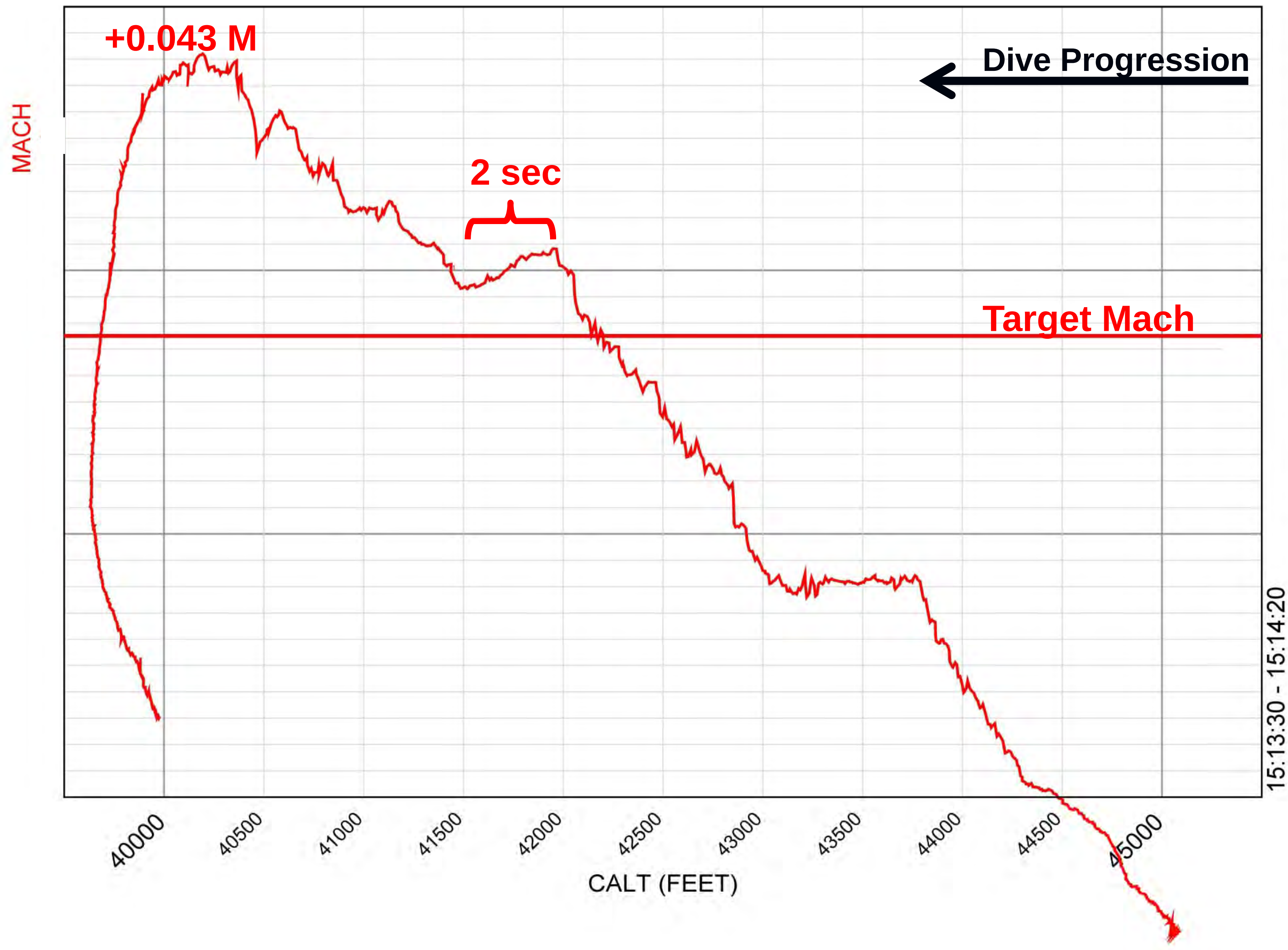
- Atmospheric Effects Compounded
- Drag Profile Changes (shakers removed)
- Standard Build-Up Sequence Dismissed
  - Straight to M_D (Low-Mid-High)



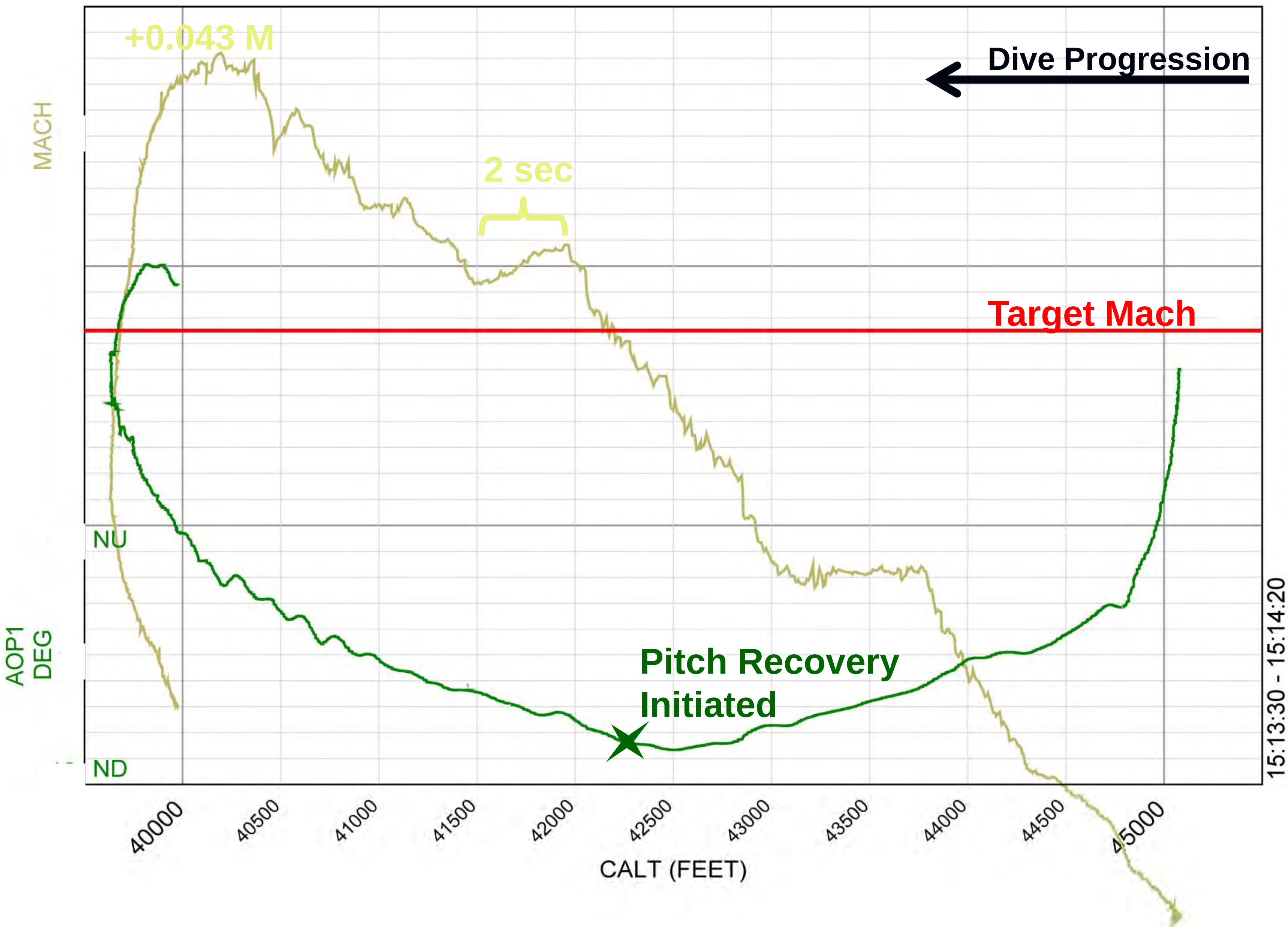
- First point targeted M_D at FL 320



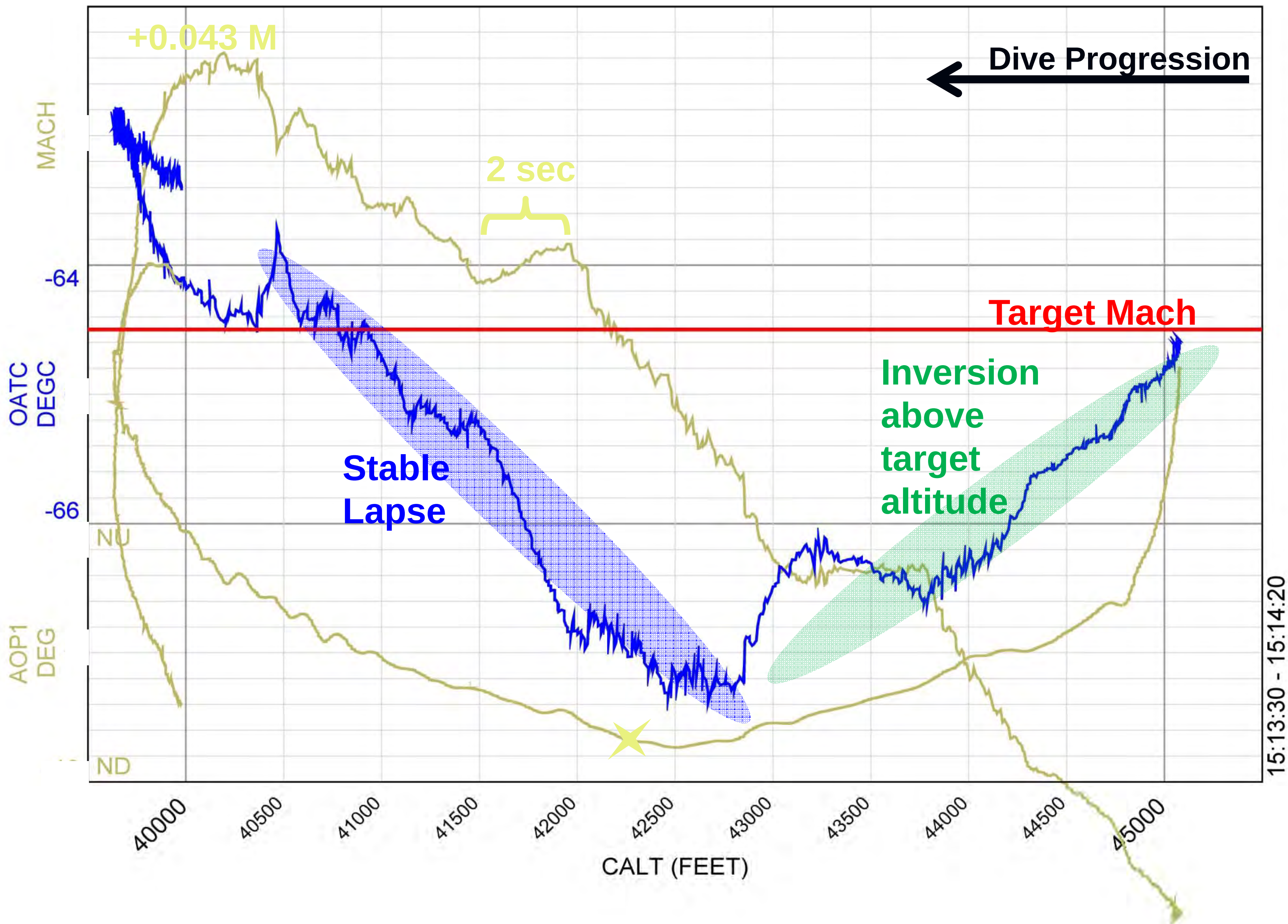
- Next point targeted M_D at FL 420



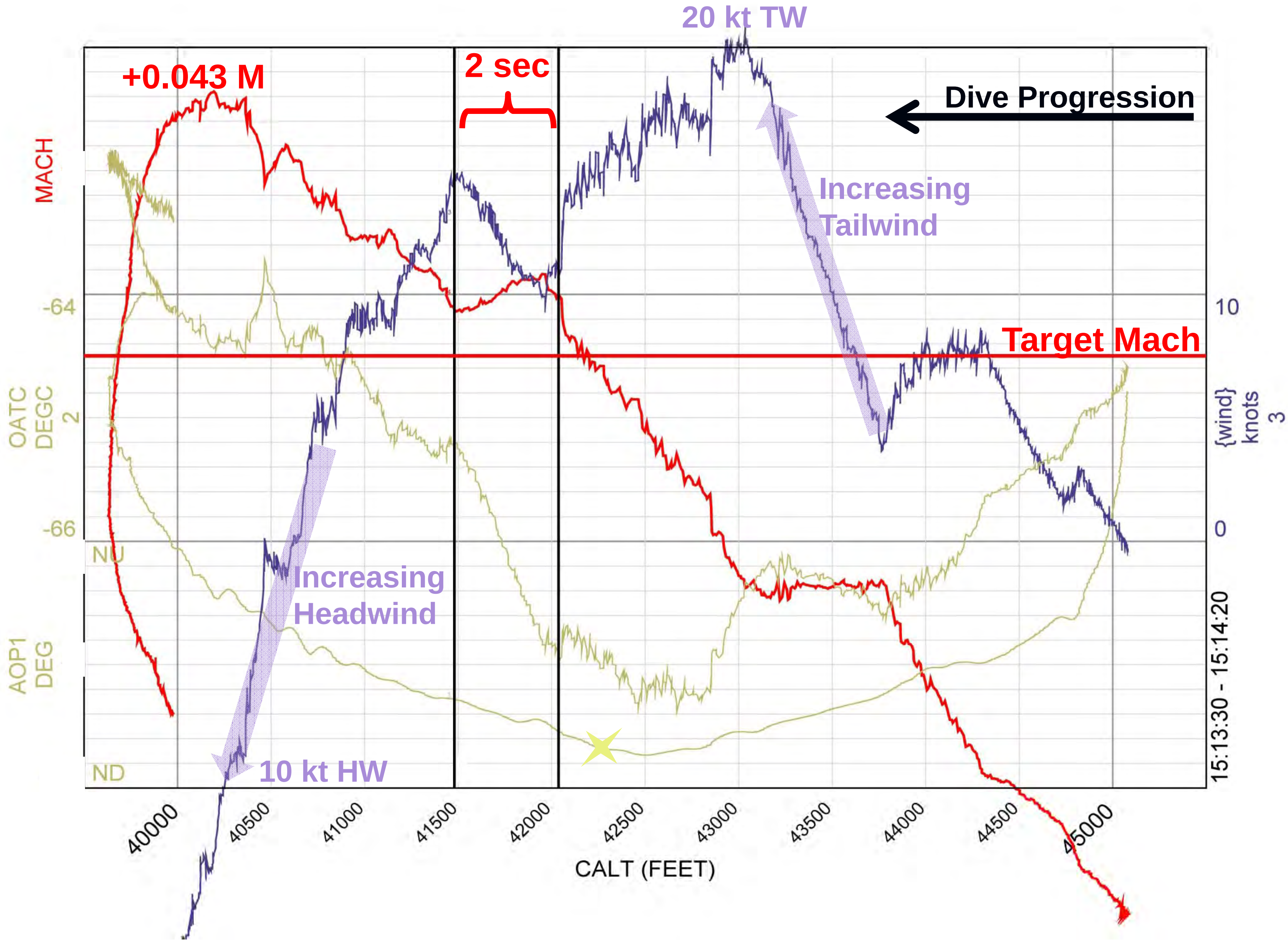
- Recovery initiated on point.



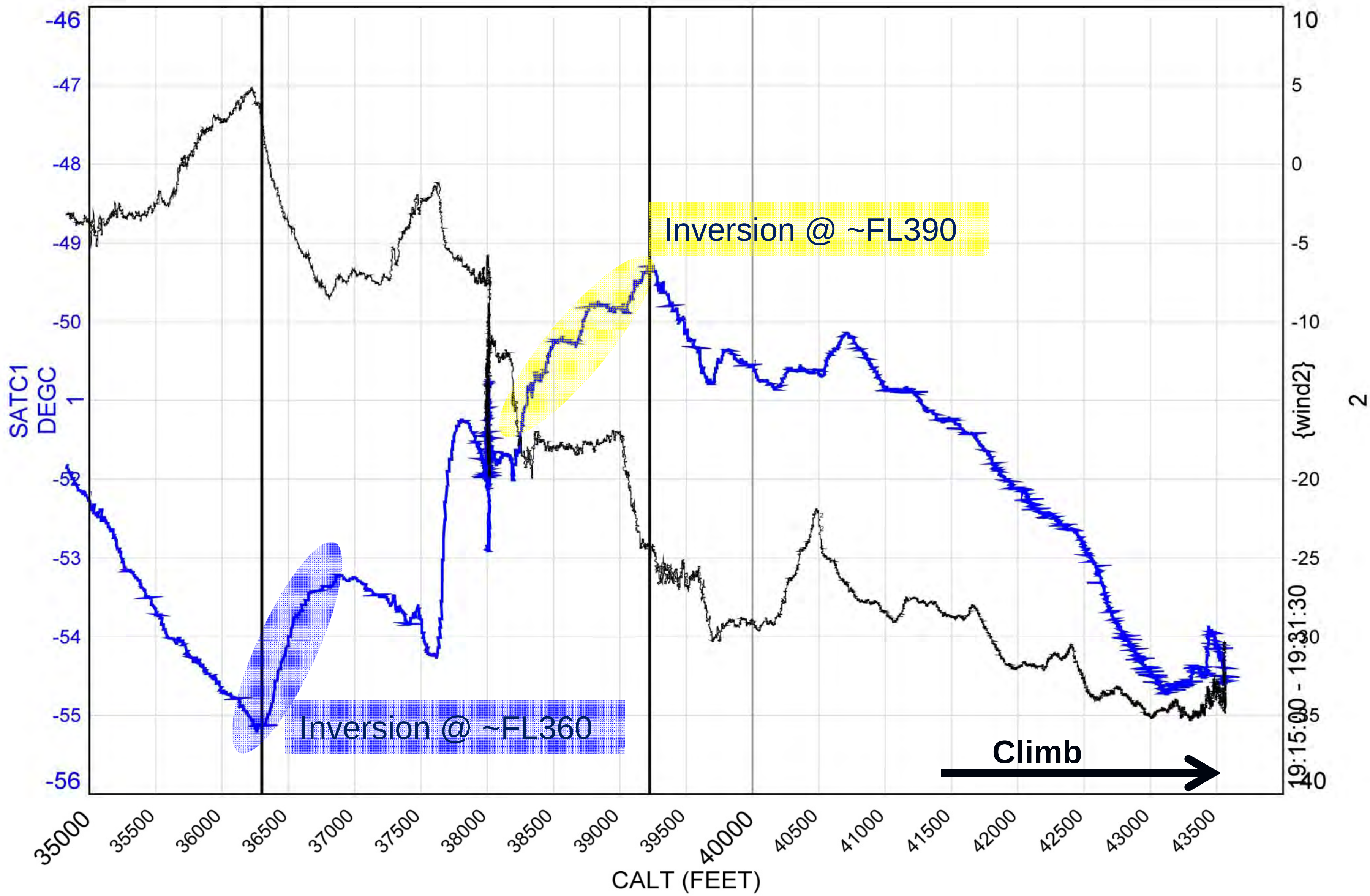
- Another inversion effect? No!



- Windshear…Windshear!

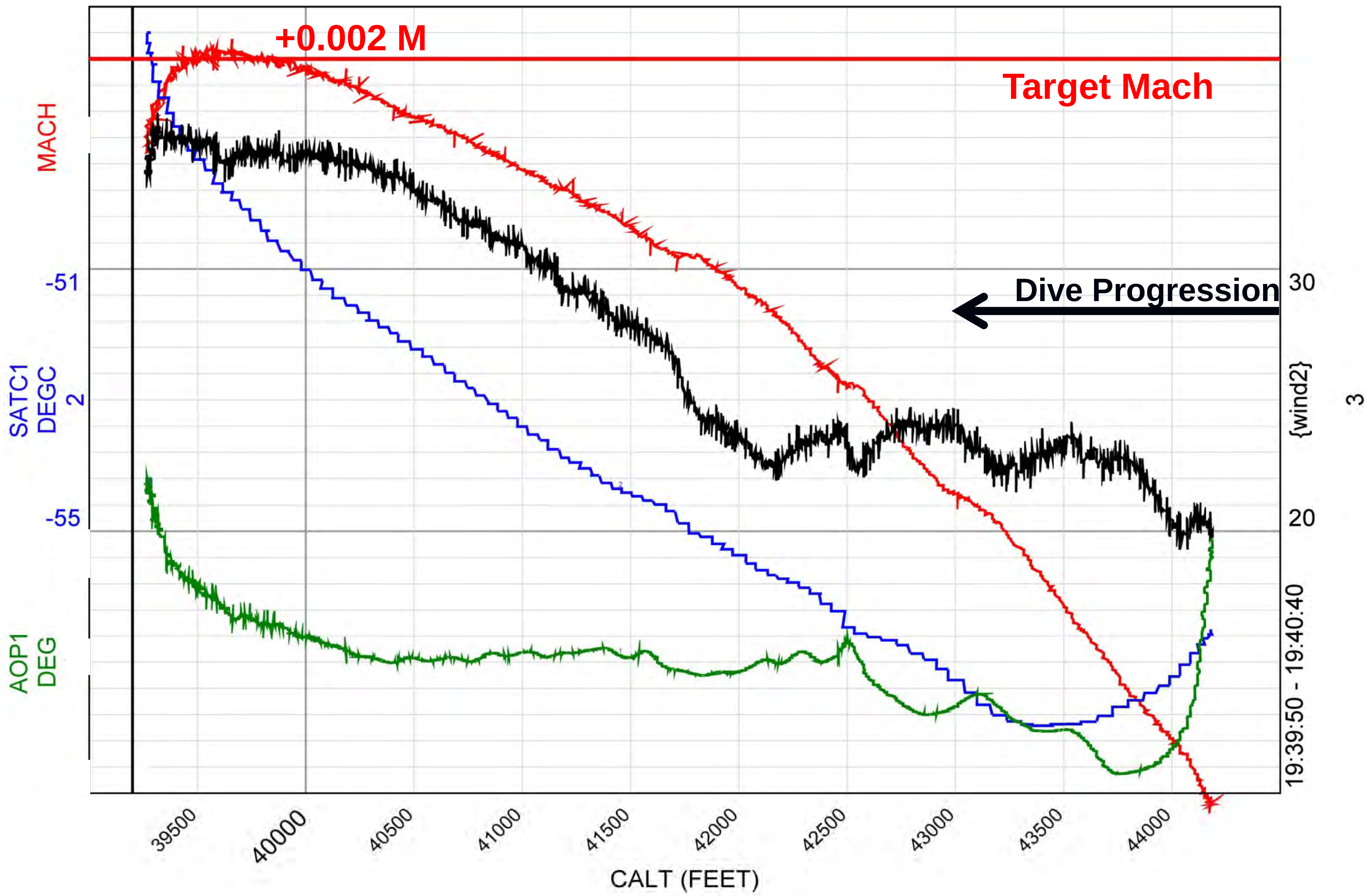



Step 5: Go Visit an Old Friend…*Relapse!*
▪"No build-up required"
▪Abort/recovery procedures/technique
▪Over-speed effects/hazards

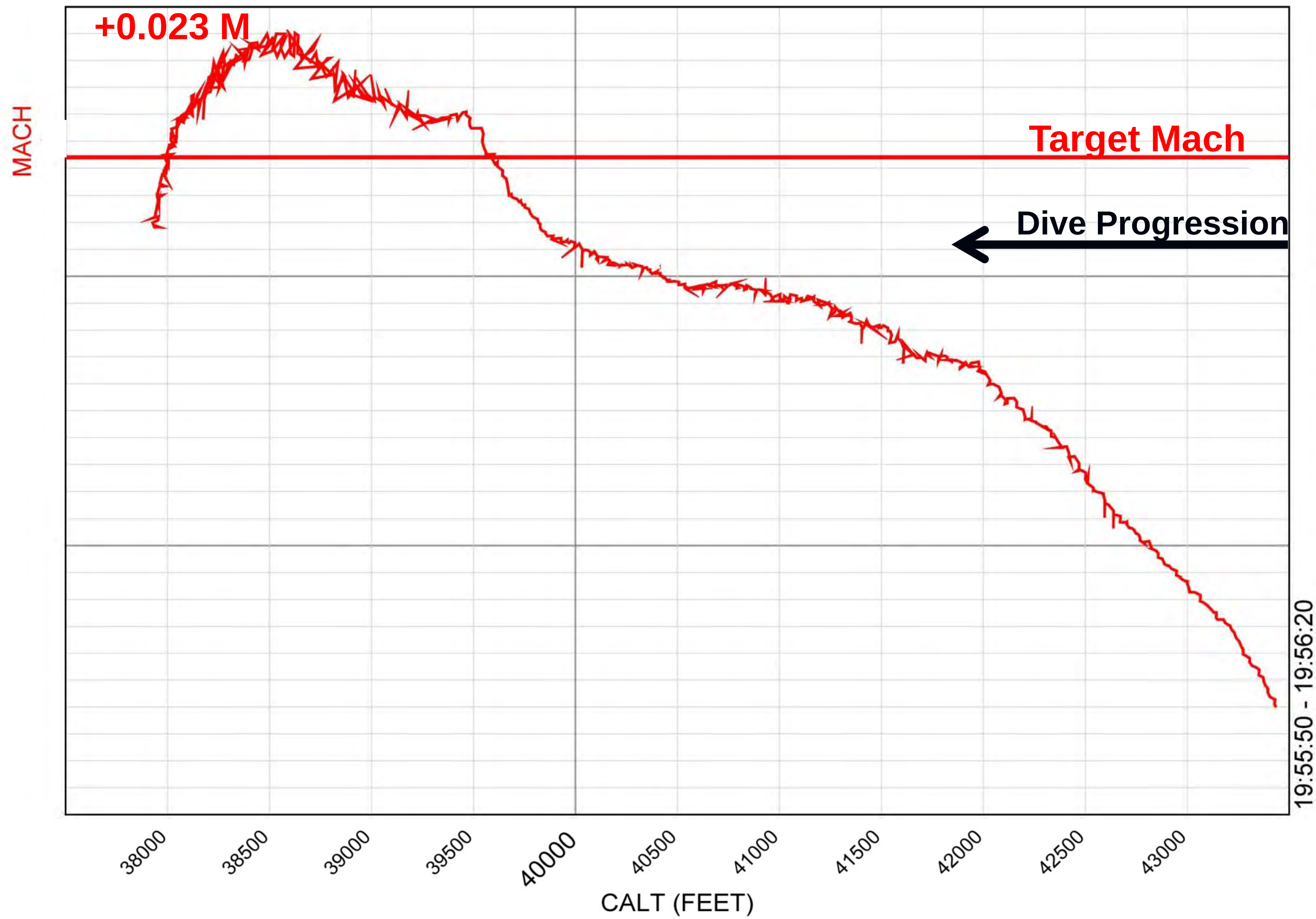


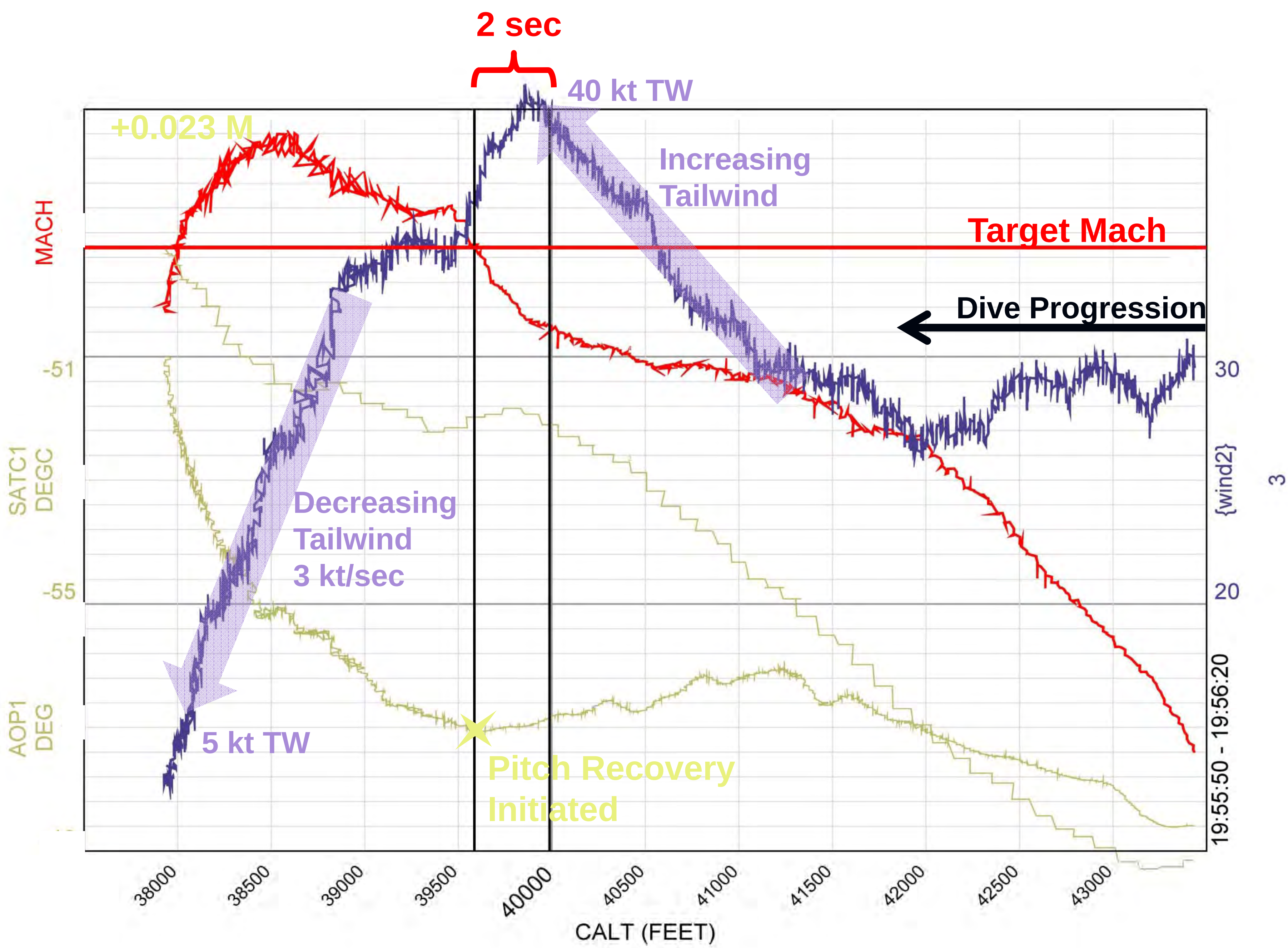
Inversion @ ~FL390
Inversion @ ~FL360
Climb
SATC1
DEGC
{wind2}
2
CALT (FEET)
19:15:00 - 19:31:30
-46
-47
-48
-49
-50
-51
-52
-53
-54
-55
-56
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
35000
35500
36000
36500
37000
37500
38000
38500
39000
39500
40000
40500
41000
41500
42000
42500
43000
43500

1st point completed in very good air with minimal overshoot.



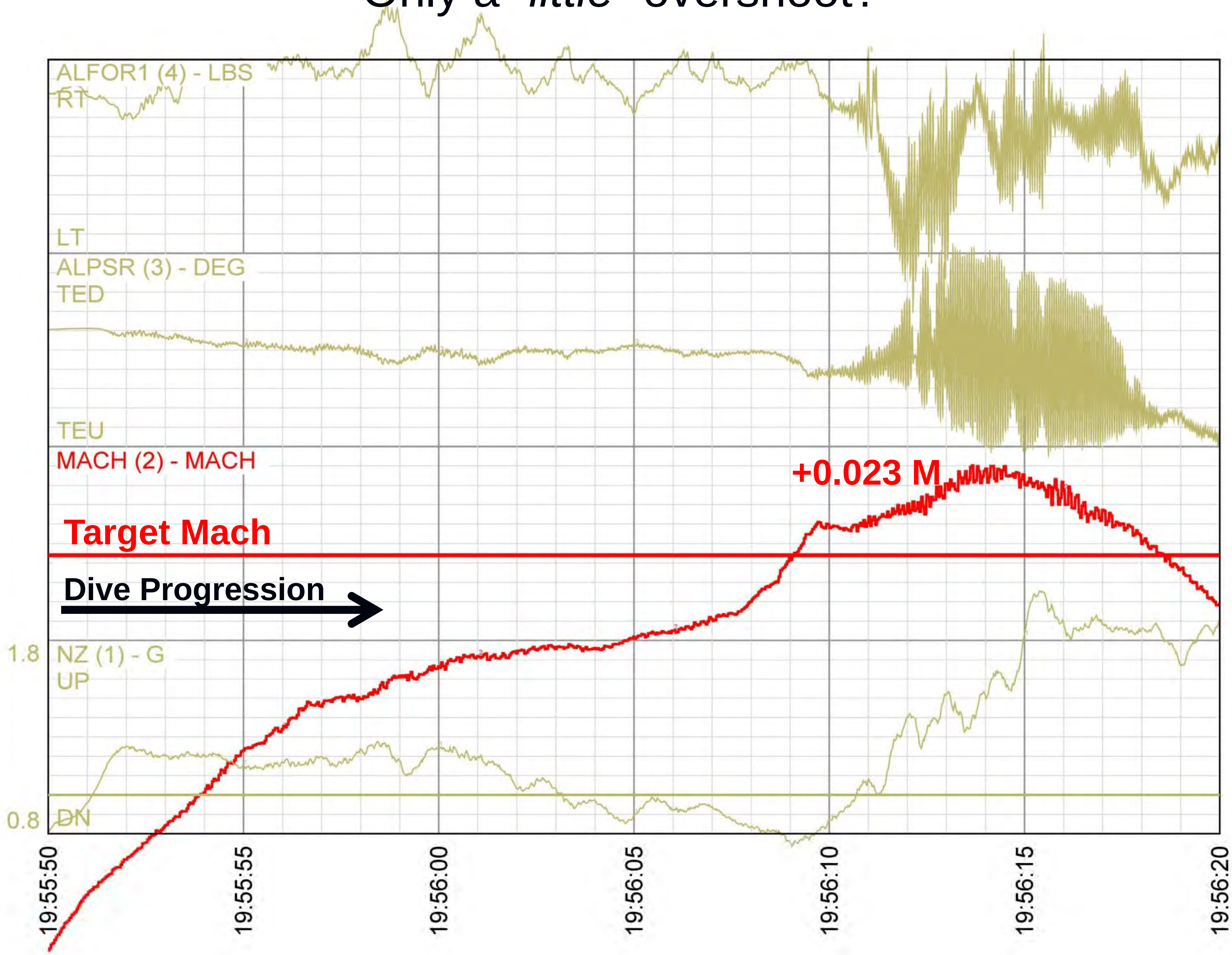
Next Dive--Only a *"little"* overshoot?



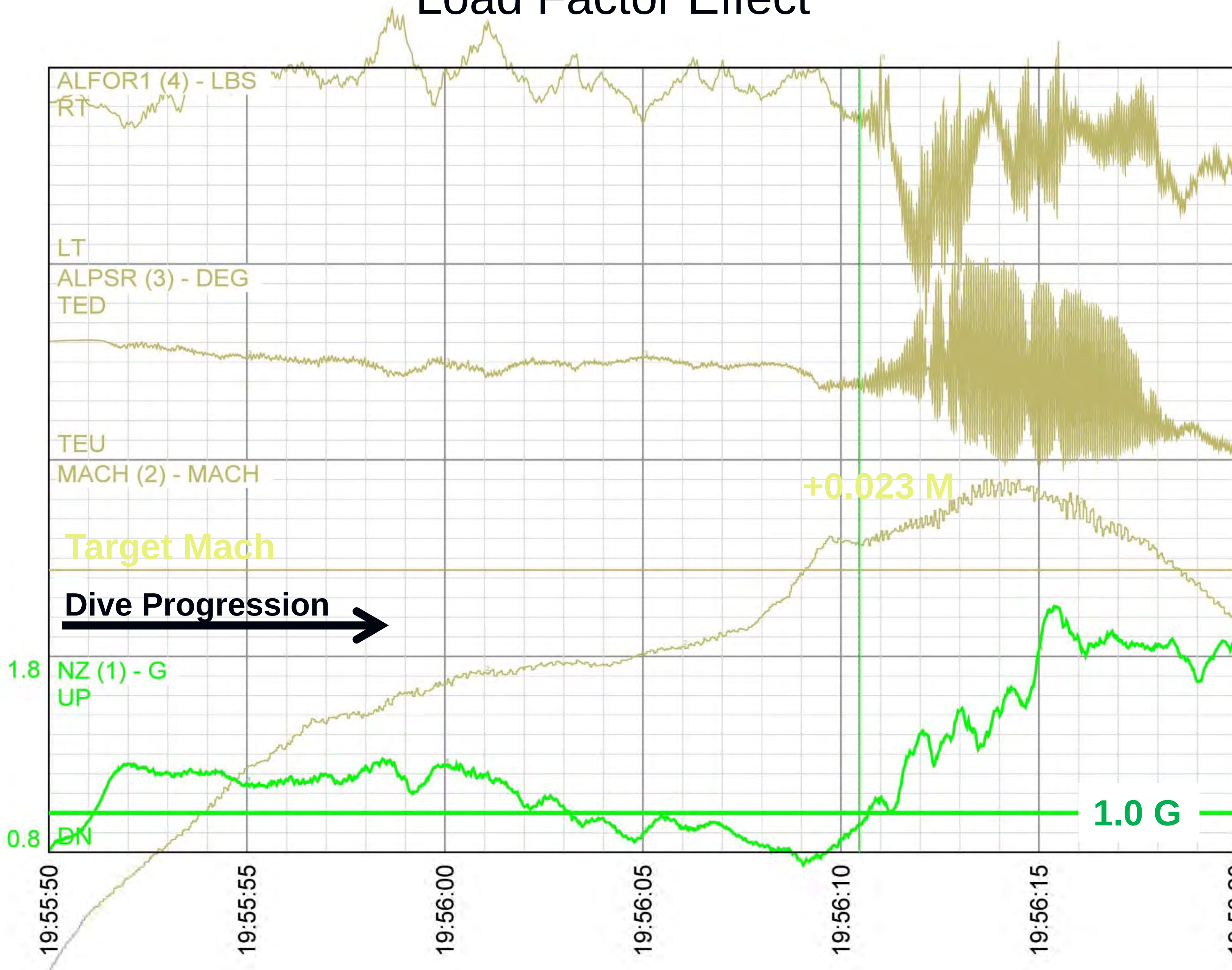


2 sec
40 kt TW
+0.023 M
Increasing
Tailwind
Target Mach
Dive Progression
MACH
-51
SATC1
DEGC
-55
AOP1
DEG
Decreasing
Tailwind
3 kt/sec
5 kt TW
Pitch Recovery
Initiated
30
20
{wind2}
3
19:55:50 - 19:56:20
38000
38500
39000
39500
40000
40500
41000
41500
42000
42500
43000
CALT (FEET)

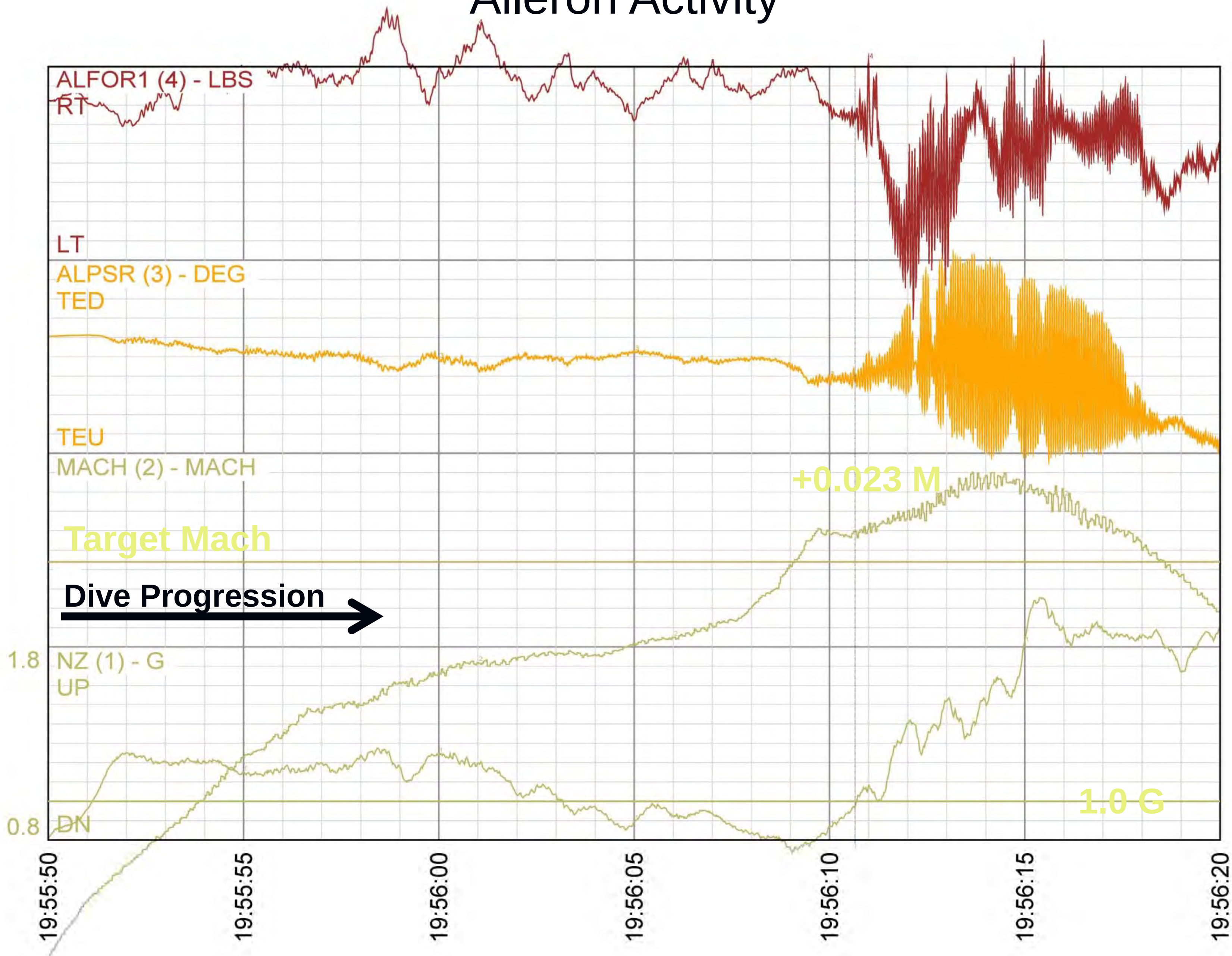
Only a *"little"* overshoot?



Load Factor Effect



Aileron Activity



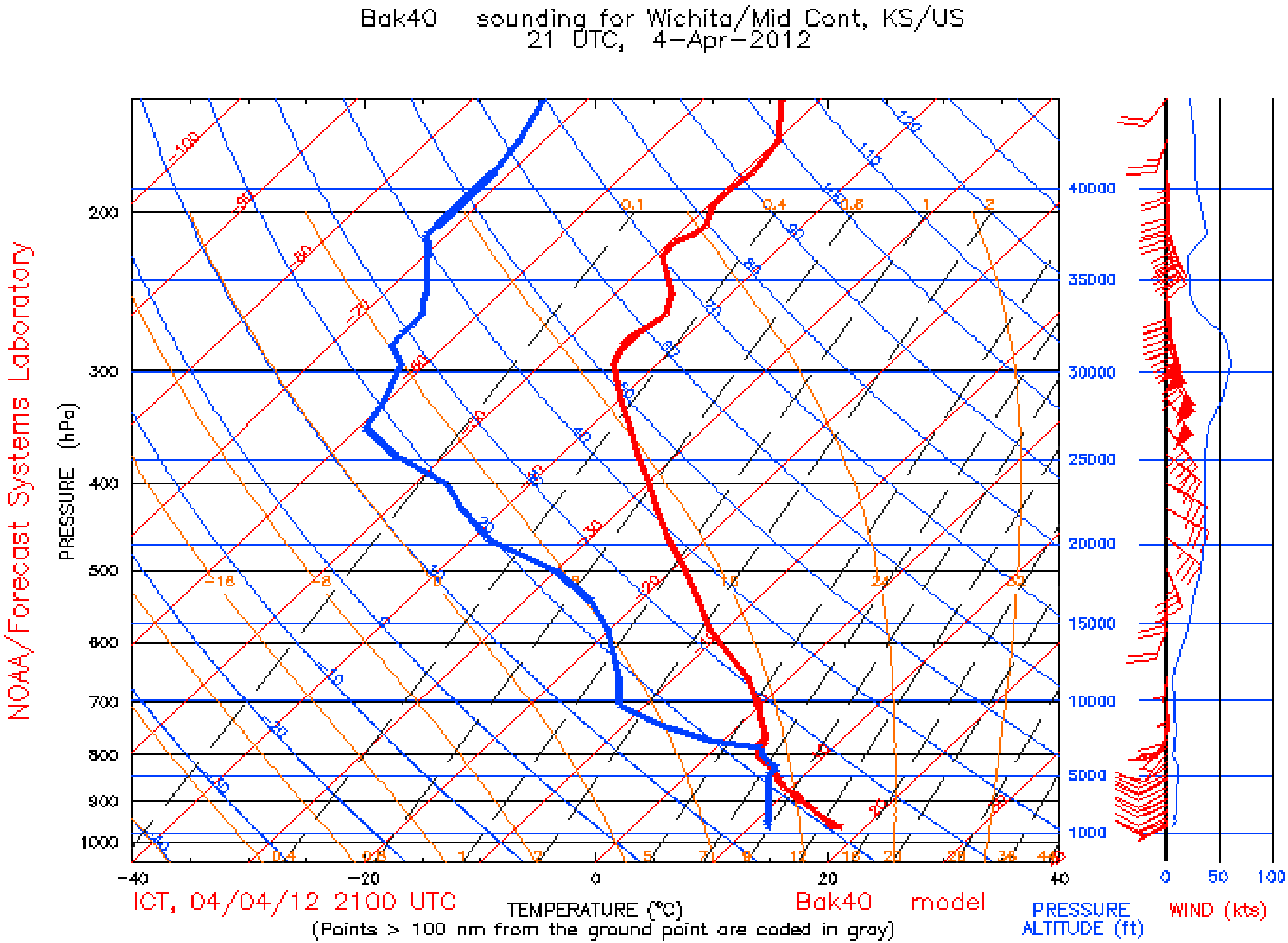
Step 6: Admit you ***still*** have a problem

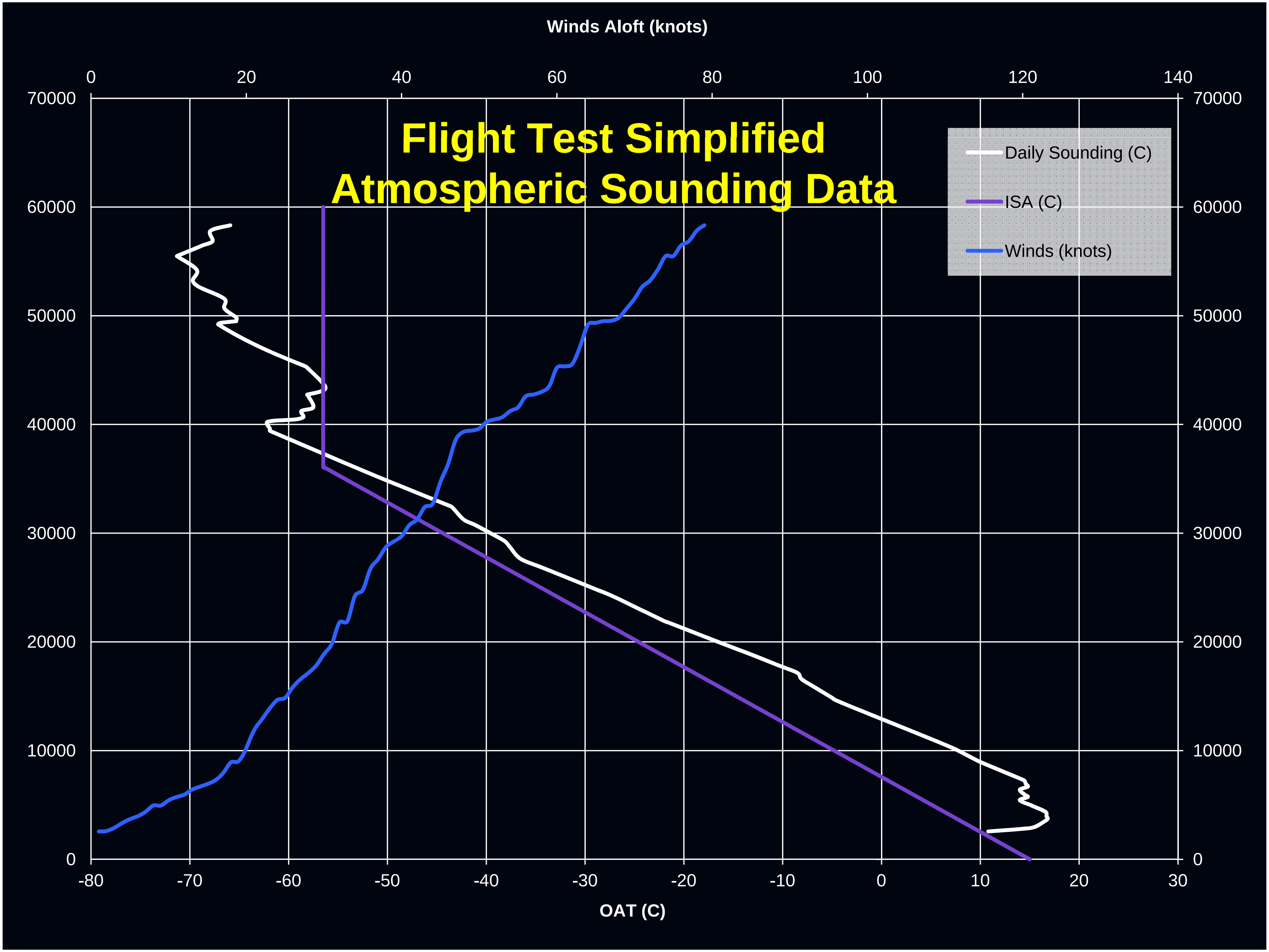
Step 7: Record *<u>& Communicate</u>* Lessons Learned

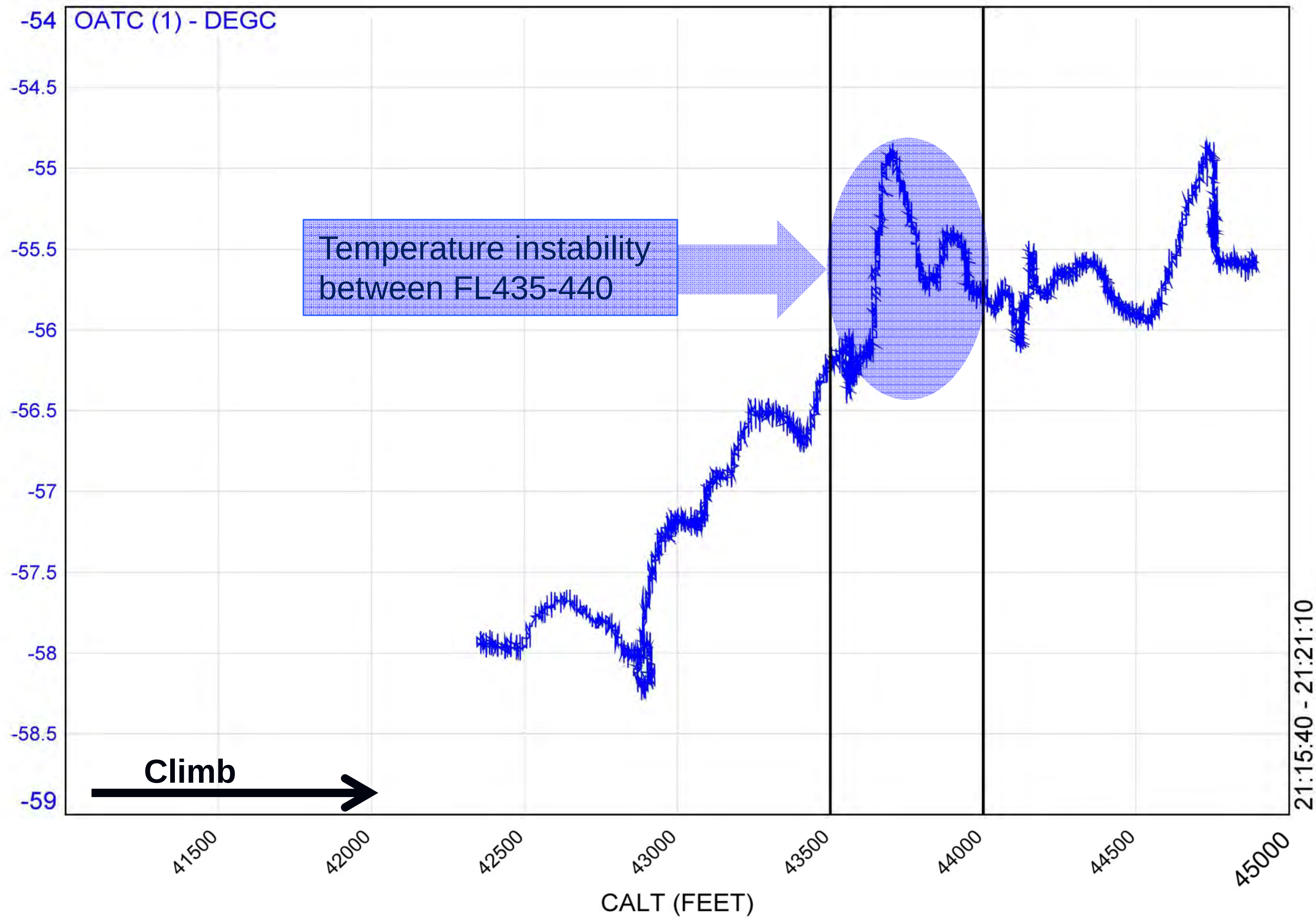
- **Detailed briefing at Quarterly safety meeting.**
- **Procedures distributed (FT WIKI/SOPs)**

Step 8: Phase 2—Atmosphere Management

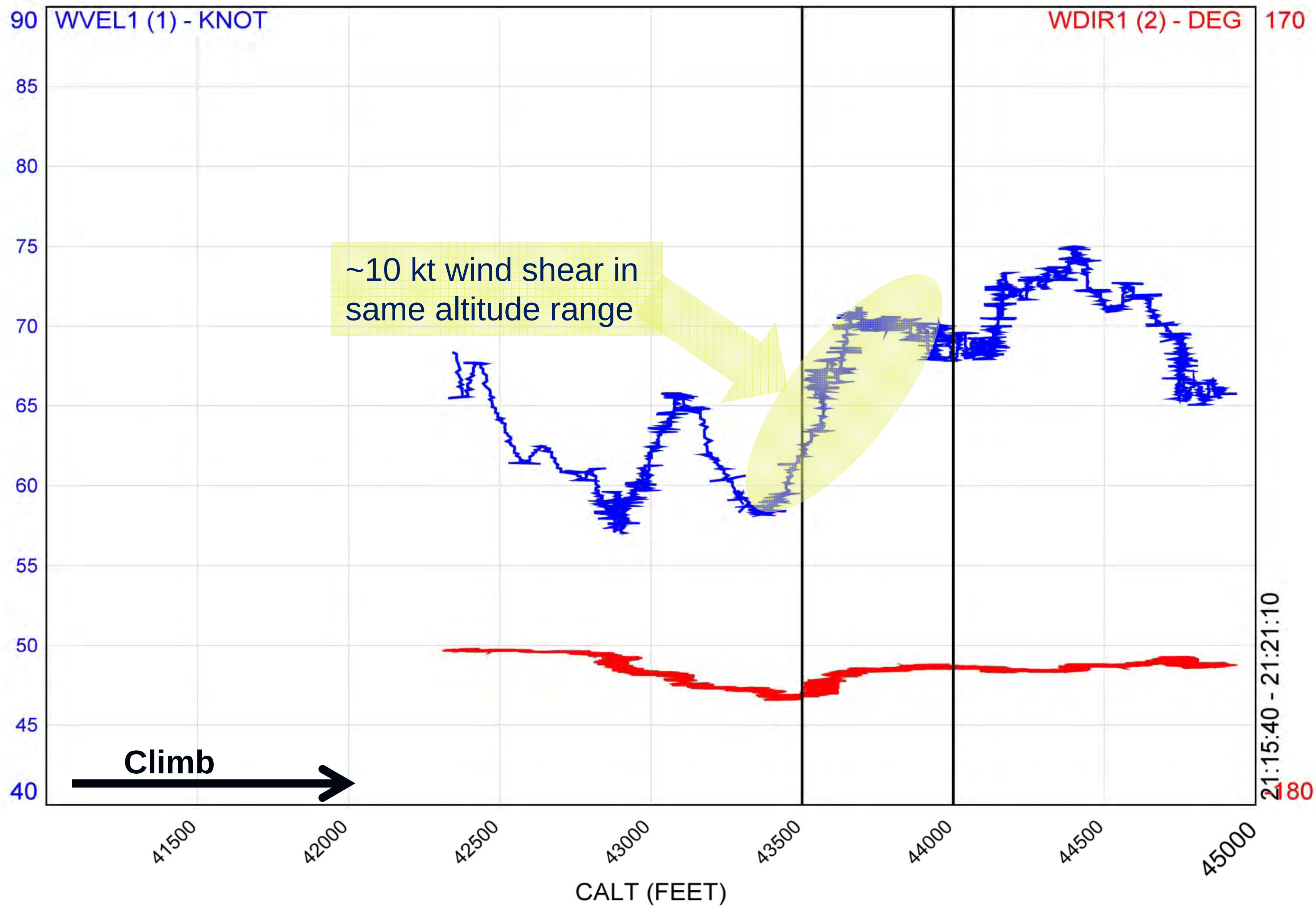
- Sounding Data: http://rucsoundings.noaa.gov/
- Dedicated TM personnel to monitor/characterize
- Undershoot targets above inversions/shear layers


Bak40 sounding for Wichita/Mid Cont, KS/US
21 UTC, 4-Apr-2012
NOAA/Forecast Systems Laboratory
PRESSURE (hPa)
ICT, 04/04/12 2100 UTC
TEMPERATURE (°C)
(Points > 100 nm from the ground point are coded in gray)
Bak40 model
PRESSURE ALTITUDE (ft)
WIND (kts)


Flight Test Simplified
Atmospheric Sounding Data
Winds Aloft (knots)
0
20
40
60
80
100
120
140
70000
60000
50000
40000
30000
20000
10000
0
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
OAT (C)
Daily Sounding (C)
ISA (C)
Winds (knots)



OATC (1) - DEGC
-54
-54.5
-55
-55.5
-56
-56.5
-57
-57.5
-58
-58.5
-59
Temperature instability between FL435-440
Climb
41500
42000
42500
43000
43500
44000
44500
45000
CALT (FEET)
21:15:40 - 21:21:10



90
85
80
75
70
65
60
55
50
45
40
WVEL1 (1) - KNOT
WDIR1 (2) - DEG
170
180
21:15:40 - 21:21:10
~10 kt wind shear in same altitude range
Climb
41500
42000
42500
43000
43500
44000
44500
45000
CALT (FEET)

Undershoot Targets…but "How Much?"

Transition time vs descent rate

- Rules-of-Thumb

  (derived from experience on recent Citation models)

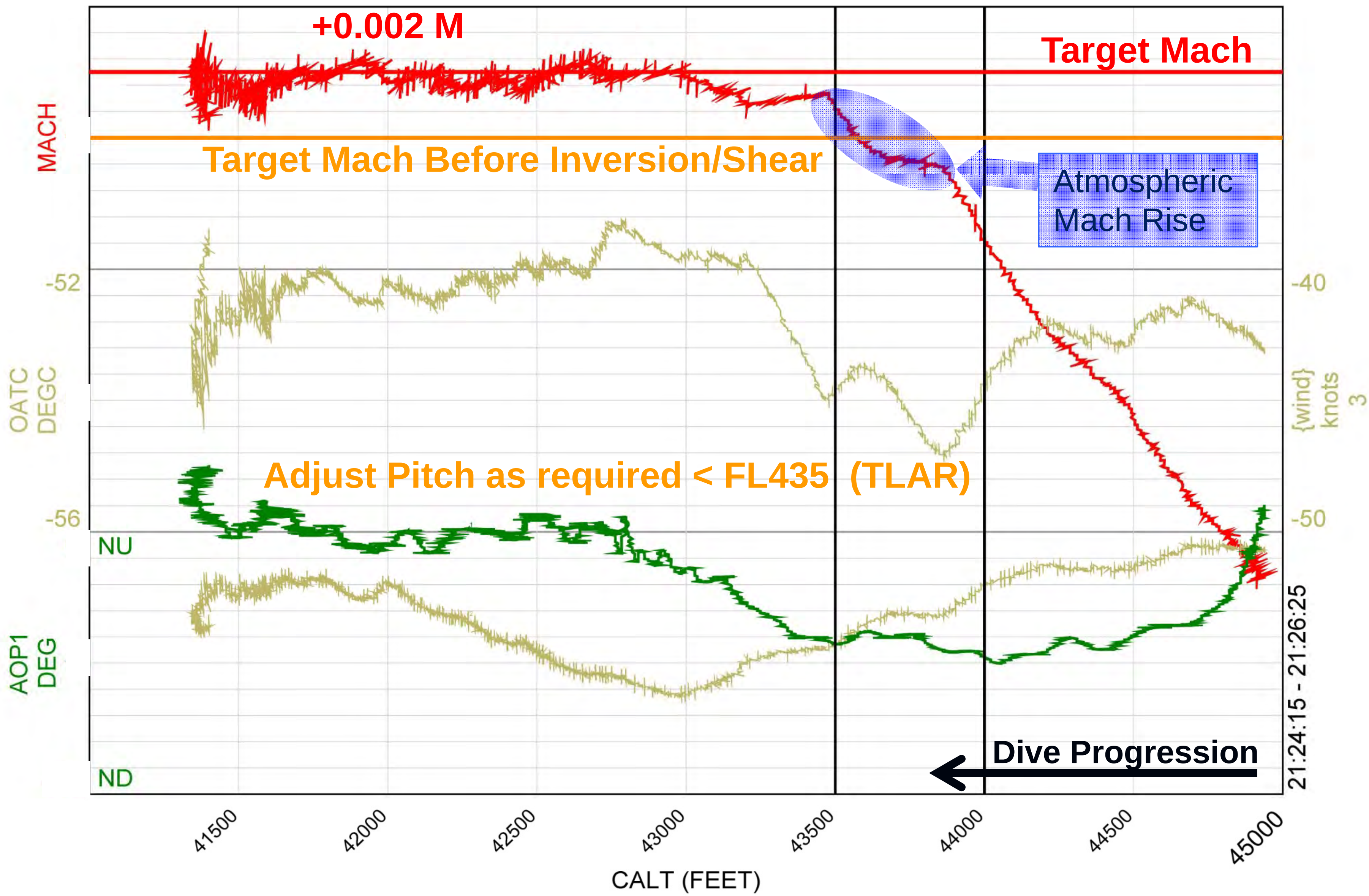
  - For every 5 kts shear, reduce target Mach above shear layer by:
    - 0.010 M (if transitioning shear layer in < 3 sec)
    - 0.005 M (~ 5 sec)
    - 0 (> 10 sec)

  - 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)**

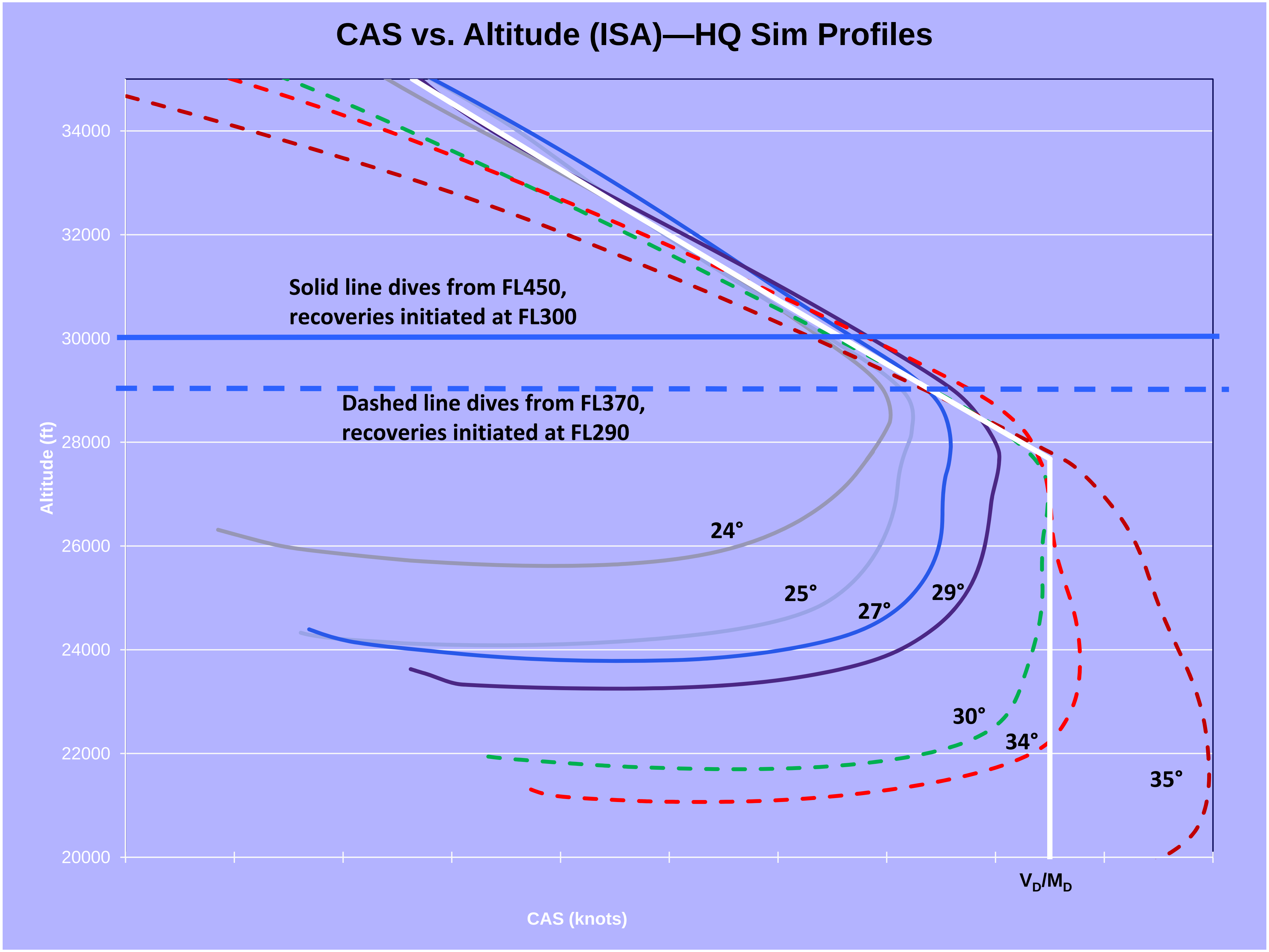


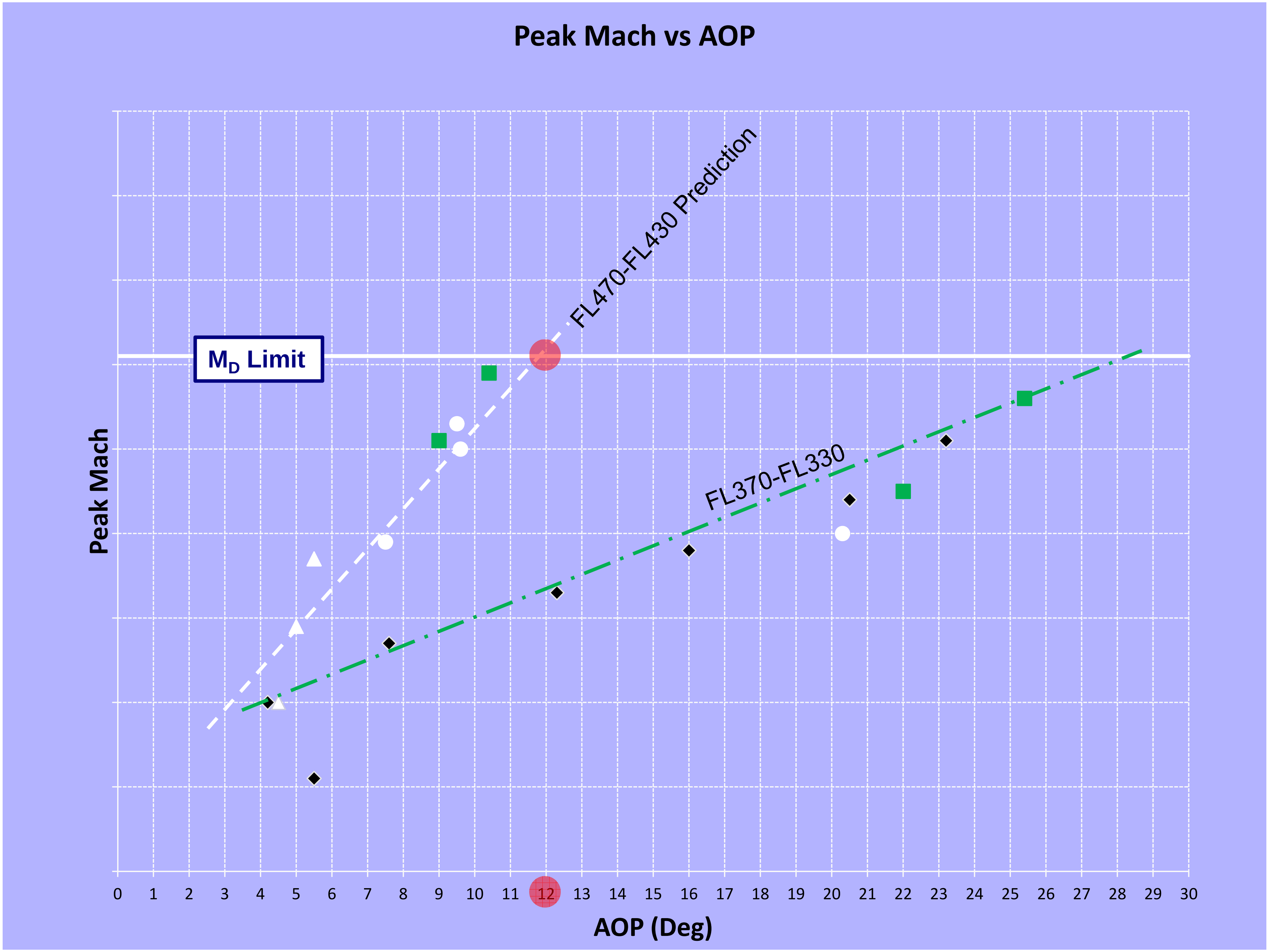
+0.002 M
Target Mach
Target Mach Before Inversion/Shear
Atmospheric Mach Rise
Adjust Pitch as required < FL435 (TLAR)
Dive Progression
MACH
OATC DEGC
AOP1 DEG
-52
-56
NU
ND
-40
-50
{wind} knots 3
21:24:15 - 21:26:25
41500
42000
42500
43000
43500
44000
44500
45000
CALT (FEET)

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
34000
32000
30000
28000
26000
24000
22000
20000
Altitude (ft)
24°
25°
27°
29°
30°
34°
35°
V_D/M_D
CAS (knots)

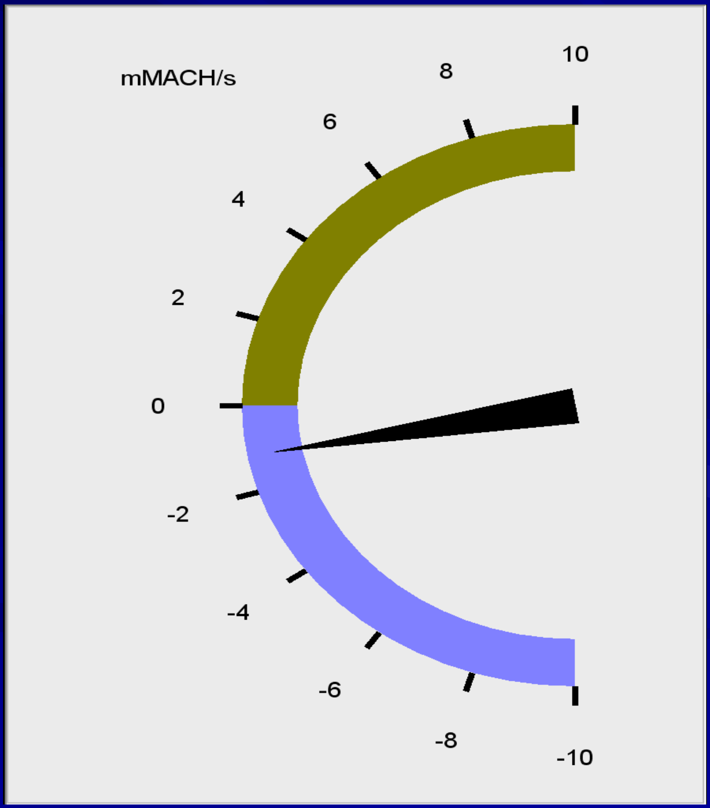


Peak Mach vs AOP
FL470-FL430 Prediction
MD Limit
FL370-FL330
Peak Mach
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
AOP (Deg)

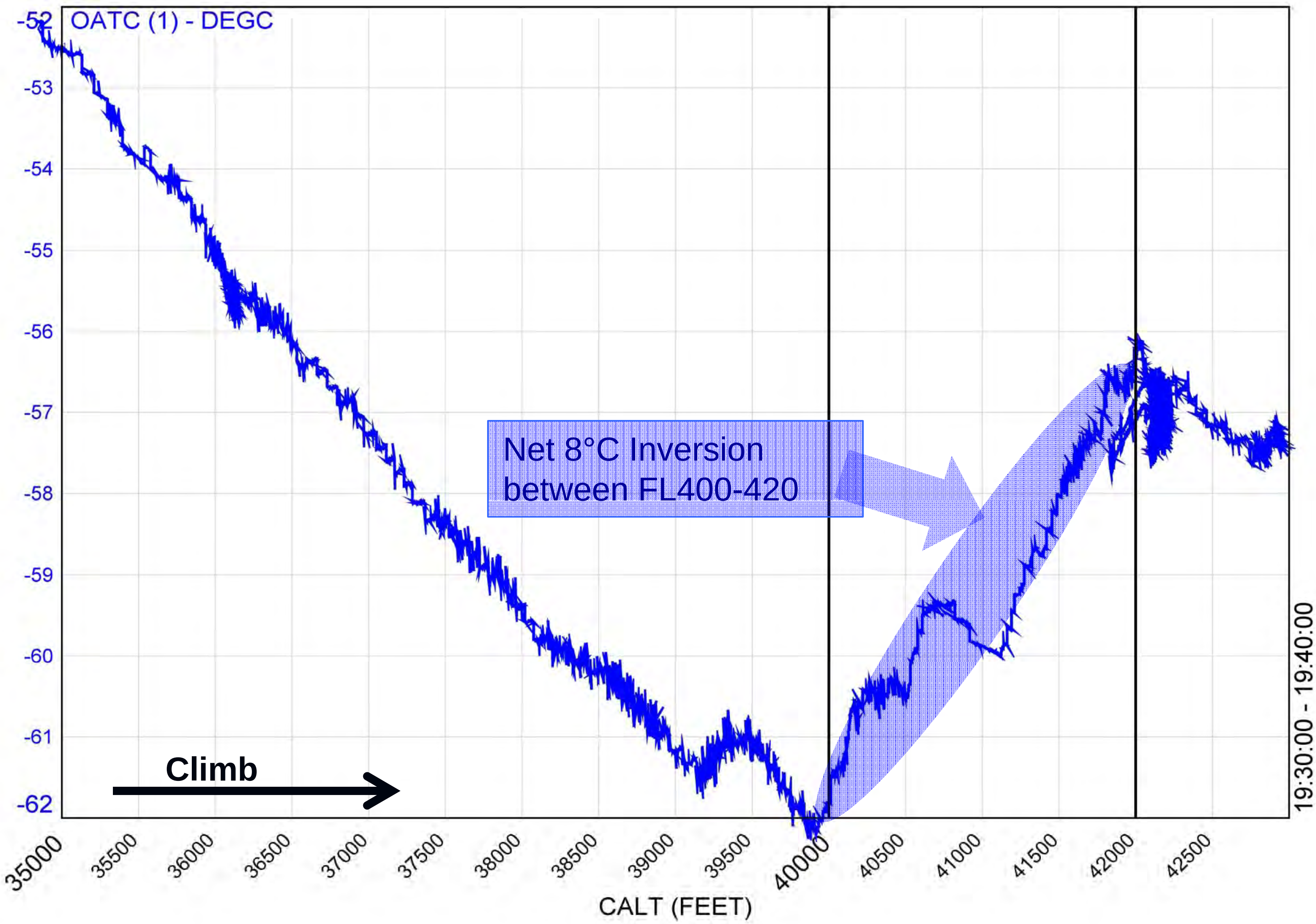
Step 10: Combined Approach

- **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.

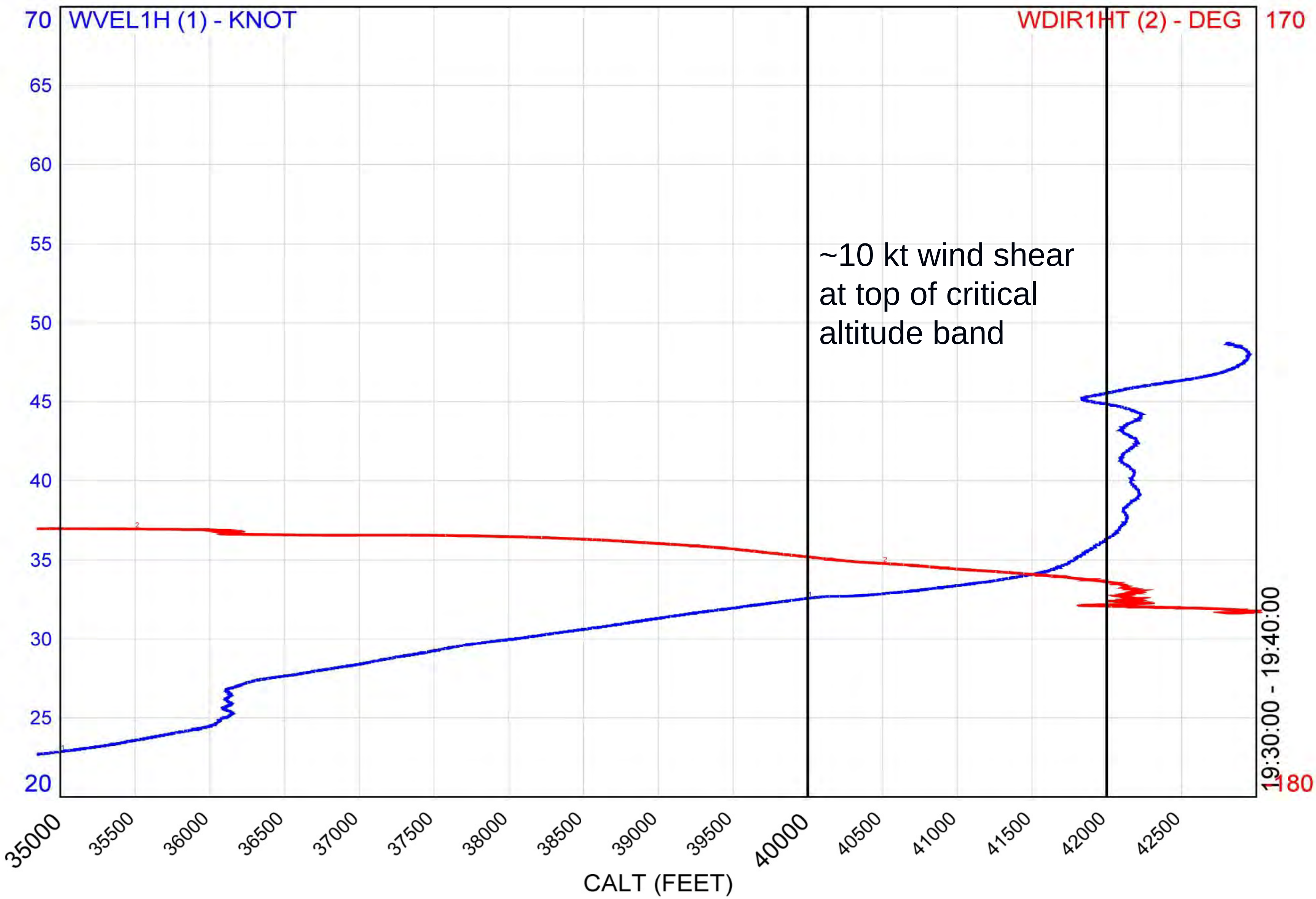
- **Mach Acceleration Parameter**
  - Mach "trend vector"

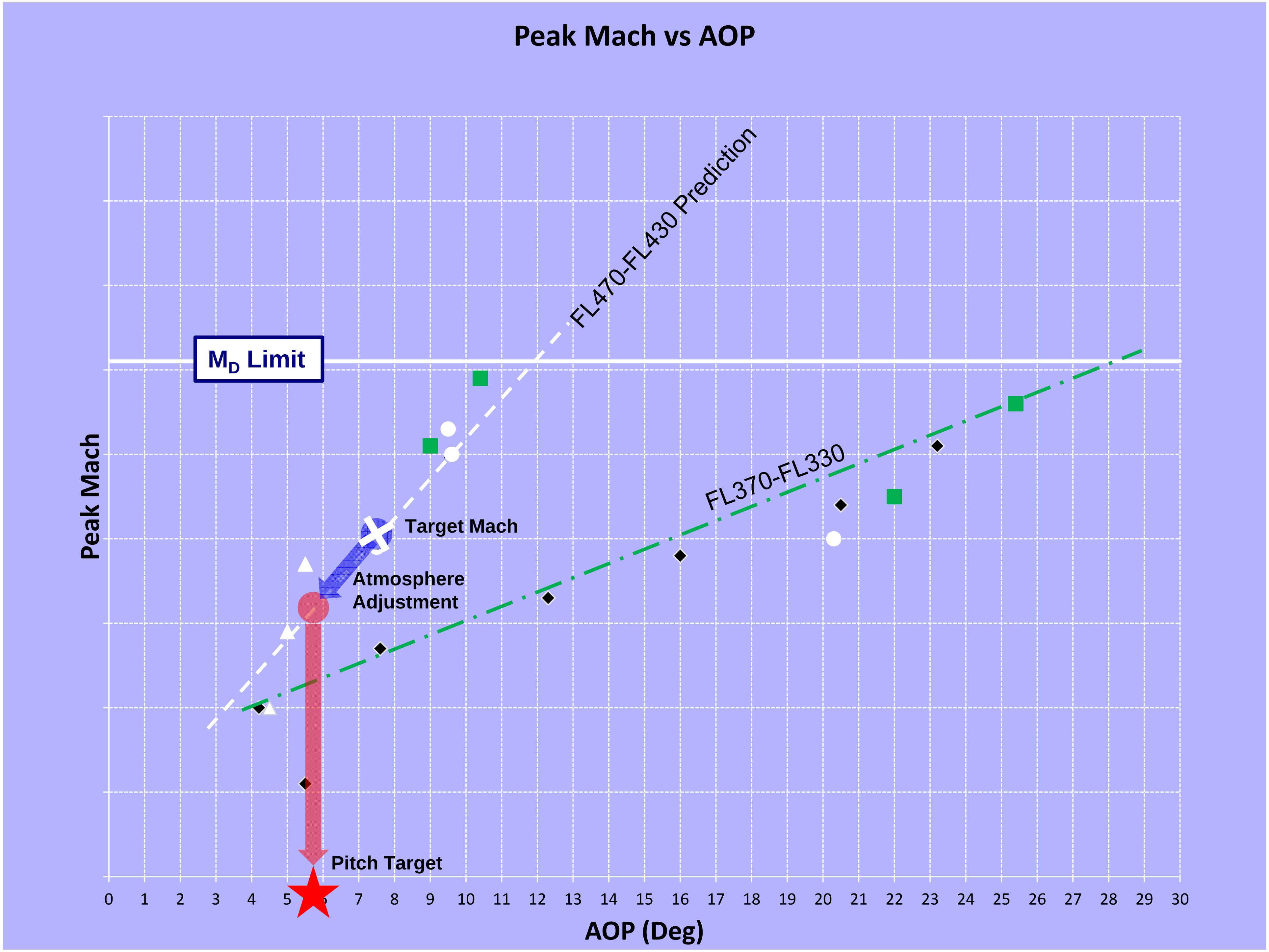


Step 11: Showtime!

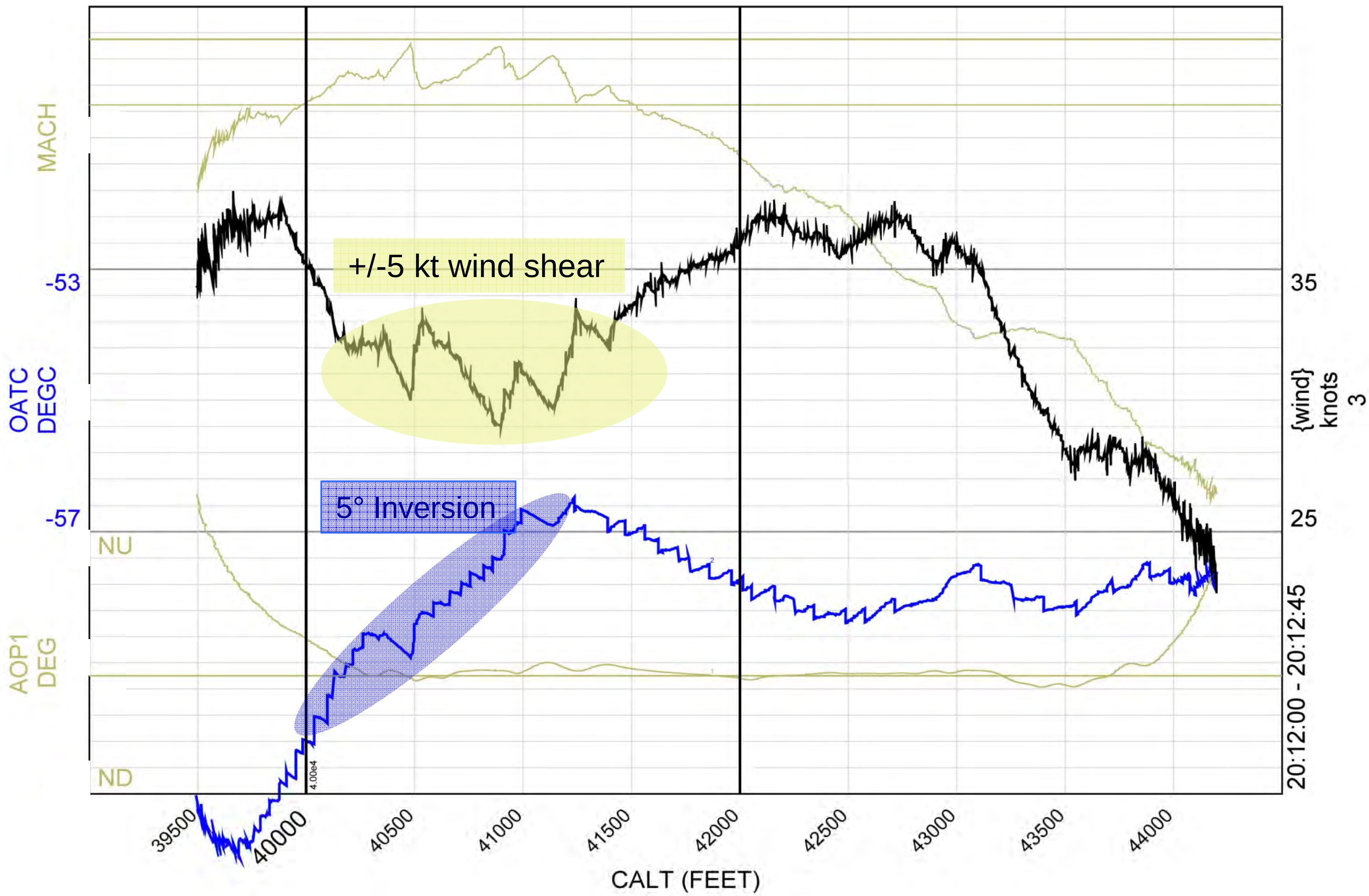


Step 11: Showtime!

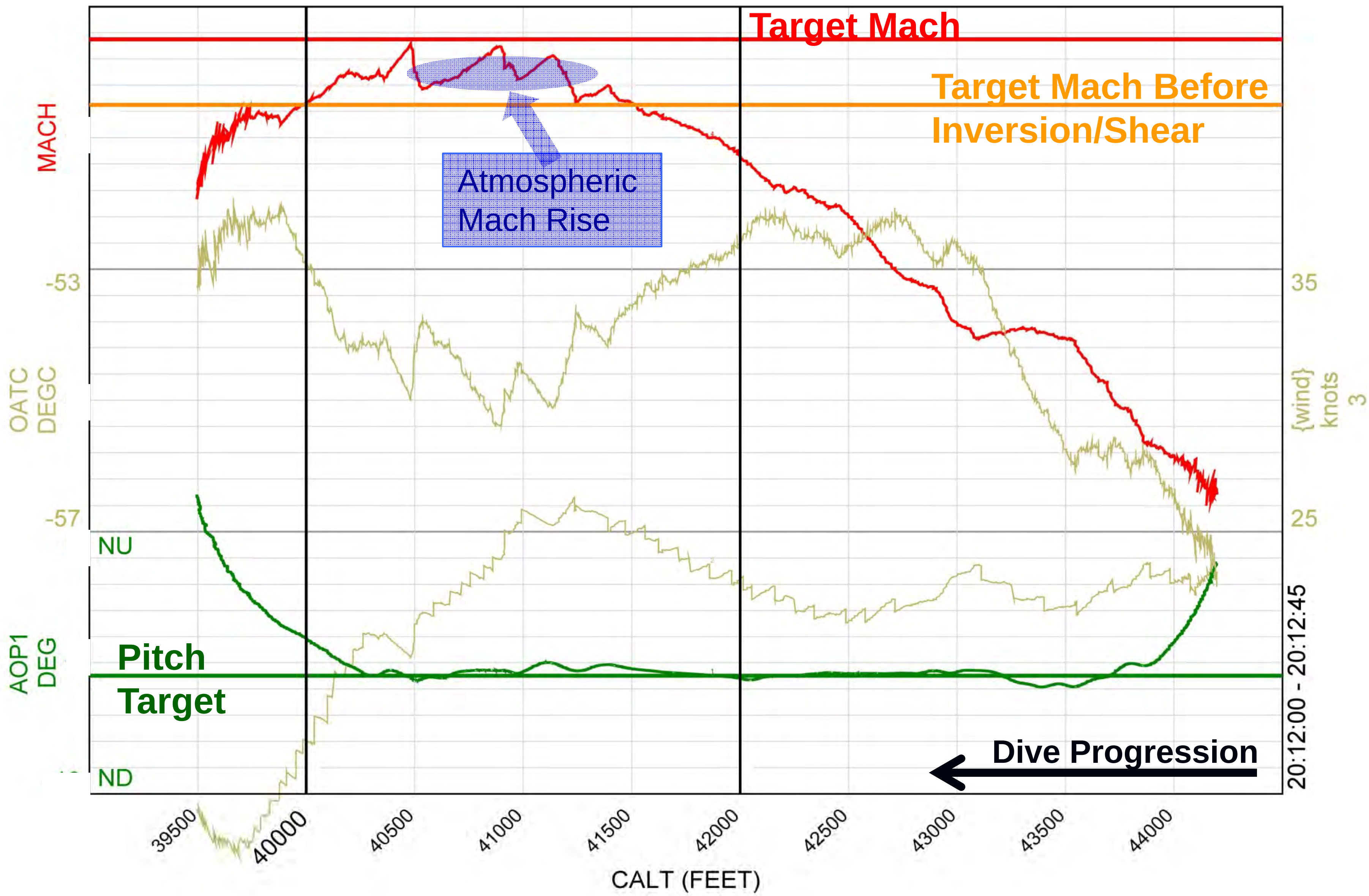




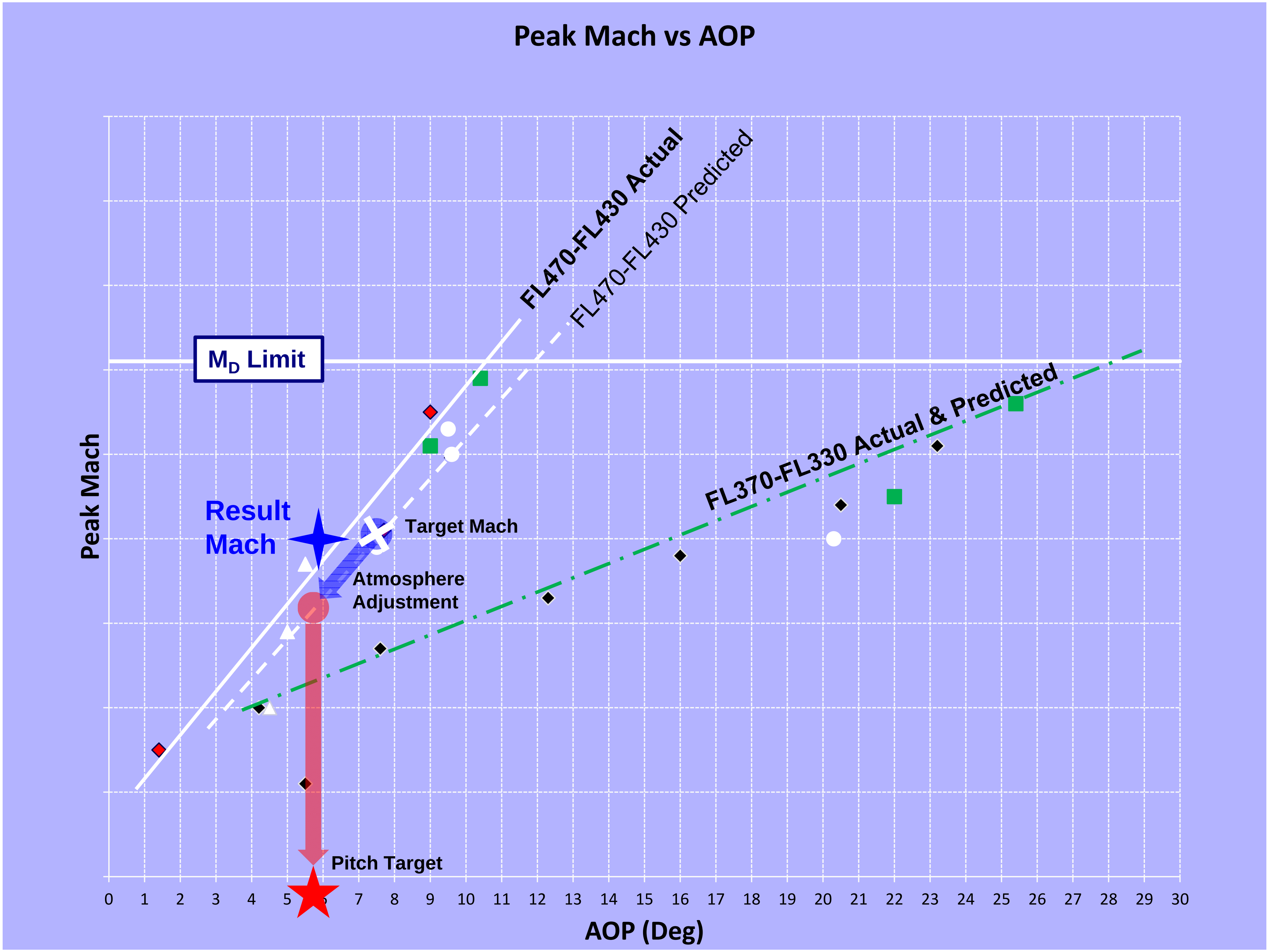
Peak Mach vs AOP
Peak Mach
AOP (Deg)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
M_D Limit
FL470-FL430 Prediction
FL370-FL330
Target Mach
Atmosphere
Adjustment
Pitch Target



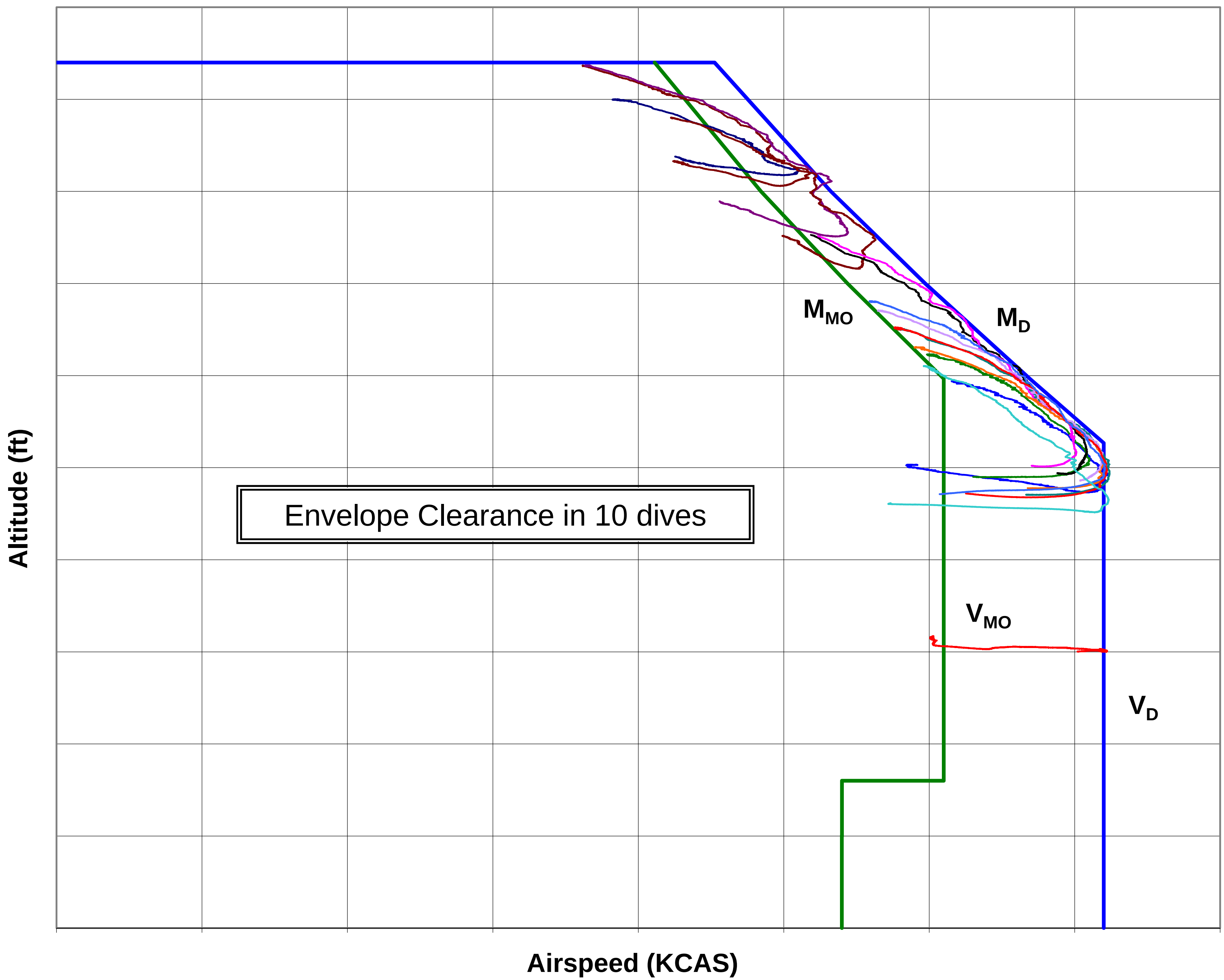
MACH
OATC
DEGC
-53
-57
NU
ND
AOP1
DEG
+/-5 kt wind shear
5° Inversion
35
25
{wind}
knots
3
20:12:00 - 20:12:45
4.00e4
39500
40000
40500
41000
41500
42000
42500
43000
43500
44000
CALT (FEET)



Target Mach
Target Mach Before Inversion/Shear
Atmospheric Mach Rise
MACH
OATC DEGC
-53
-57
NU
ND
AOP1 DEG
Pitch Target
Dive Progression
35
25
{wind} knots 3
20:12:00 - 20:12:45
39500
40000
40500
41000
41500
42000
42500
43000
43500
44000
CALT (FEET)



Peak Mach vs AOP
Peak Mach
AOP (Deg)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
FL470-FL430 Actual
FL470-FL430 Predicted
FL370-FL330 Actual & Predicted
M_D Limit
Result Mach
Target Mach
Atmosphere Adjustment
Pitch Target



M_MO
M_D
Envelope Clearance in 10 dives
V_MO
V_D
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