Flight Test Safety Workshop
27-30 April 2009
Ottawa, Ontario, Canada

777 Freighter
Aileron Vibration Occurrence

Flight Test Safety Workshop
Ottawa, Ontario, Canada
April 29-30, 2009

Van Chaney, Boeing 777 Deputy Chief Pilot
Paul Bolds-Moorehead, Boeing 777 Stability & Control Senior Lead Engineer

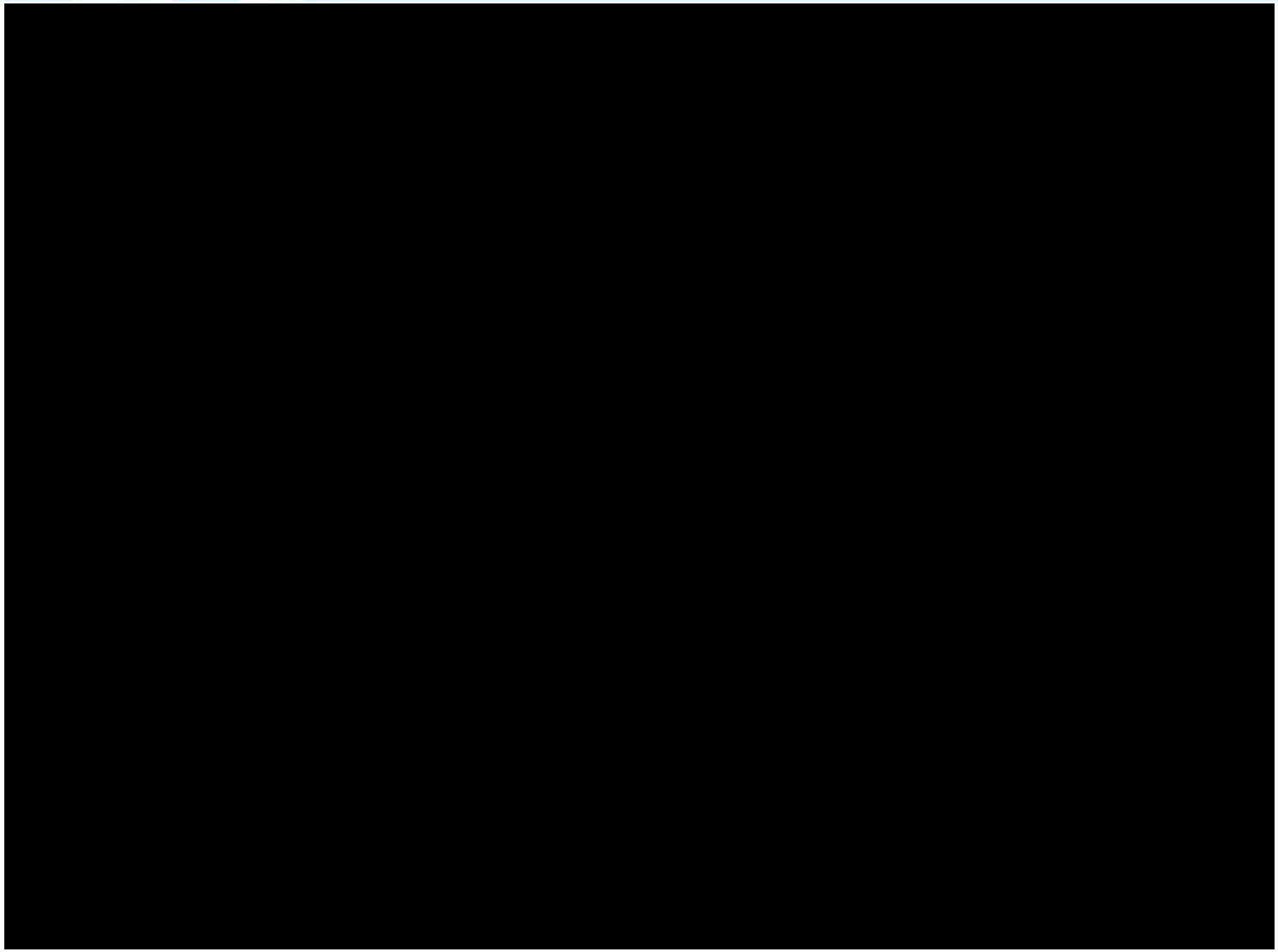
Agenda

- Introductions
- 777F airplane description/background
- Original flight test plans
- Aileron vibration discovery flights
- To fix or not to fix ?
- Re-test flights
- Lessons Learned
- Summary

Agenda

- Introductions
- 777F airplane description/background
- Original flight test plans
- Aileron vibration discovery flights
- To fix or not to fix ?
- Re-test flights
- Lessons Learned
- Summary

777 Freighter First Flight



777 Introduction
Family Evolution

777-200
1995

535,000-lb TOW
74k-84k Thrust

777-200IGW
1997

632,500-lb TOW
84k-90k Thrust

777-200ER
1998

648,000-lb TOW
≤ 90k Thrust

777-200ER
2000

656,000-lb TOW
≤ 94k Thrust

777-200LR
2006

766,000-lb TOW
110k & 115k Thrust

777F
2009

766,000-lb TOW
110k & 115k Thrust

777-300
1998

660,000-lb TOW
84k-98k Thrust

777-300ER
2004

775,000-lb TOW
115k Thrust

Summary of Changes: 777-200LR to 777F

MTOW 766,800 lb (***with revised c.g. envelope***)
MLW 575,000 lb (a 17% increase)

No aerodynamic changes

- **Same wing**
- **Same fuselage**
- **Same empennage**

Addition of Maneuver Load Alleviation (MLA) function in Primary Flight Computers

777F Airplane Description
Flight Envelope

V_{MO} / M_{MO} ~ MAXIMUM OPERATING LIMIT SPEED

V_{FC} / M_{FC} ~ MAXIMUM SPEED FOR STABILITY CHARACTERISTICS

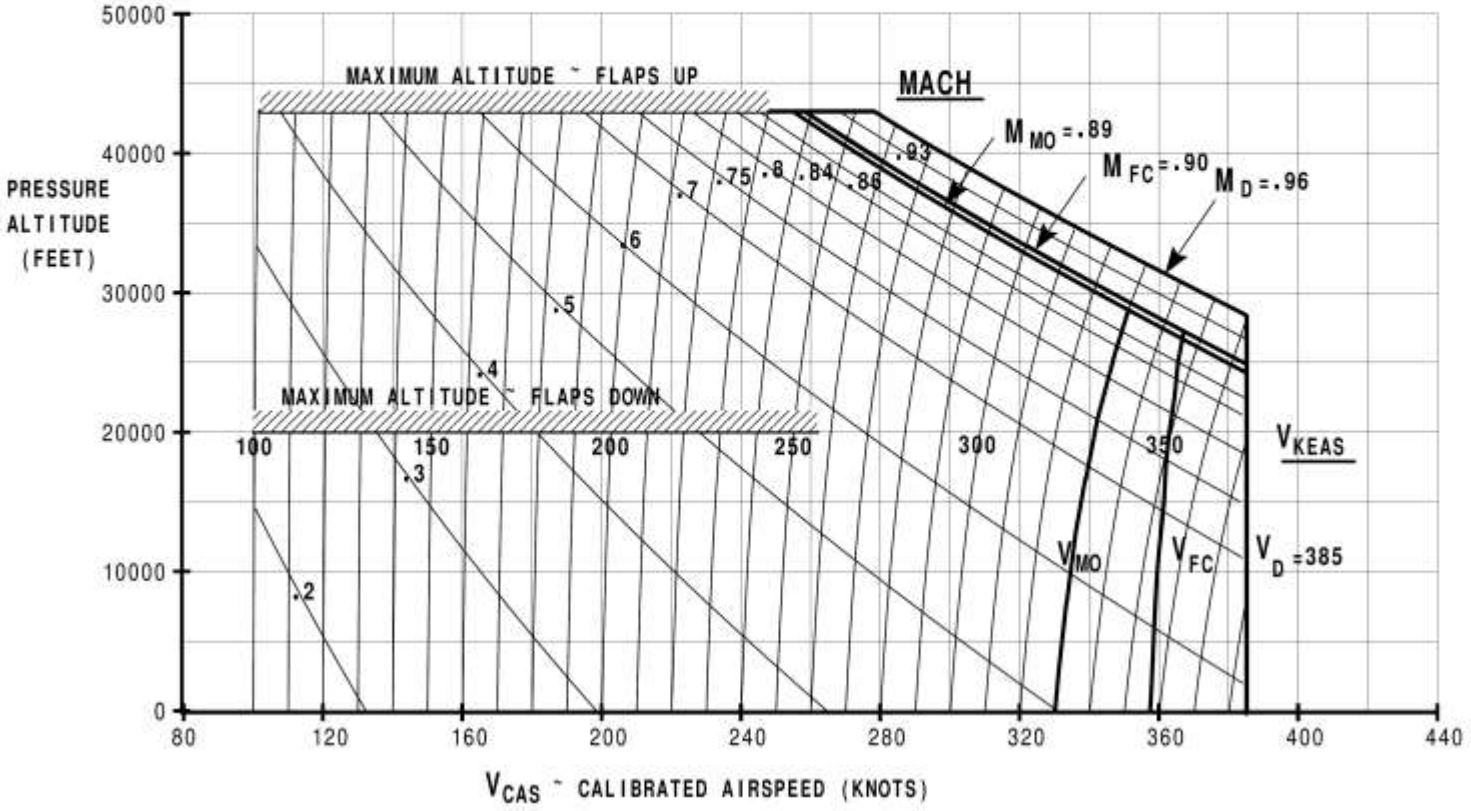
V_D / M_D ~ DESIGN DIVE SPEED

V_{LO} / V_{LE} = 270 KEAS ~ GEAR OPERATING SPEED

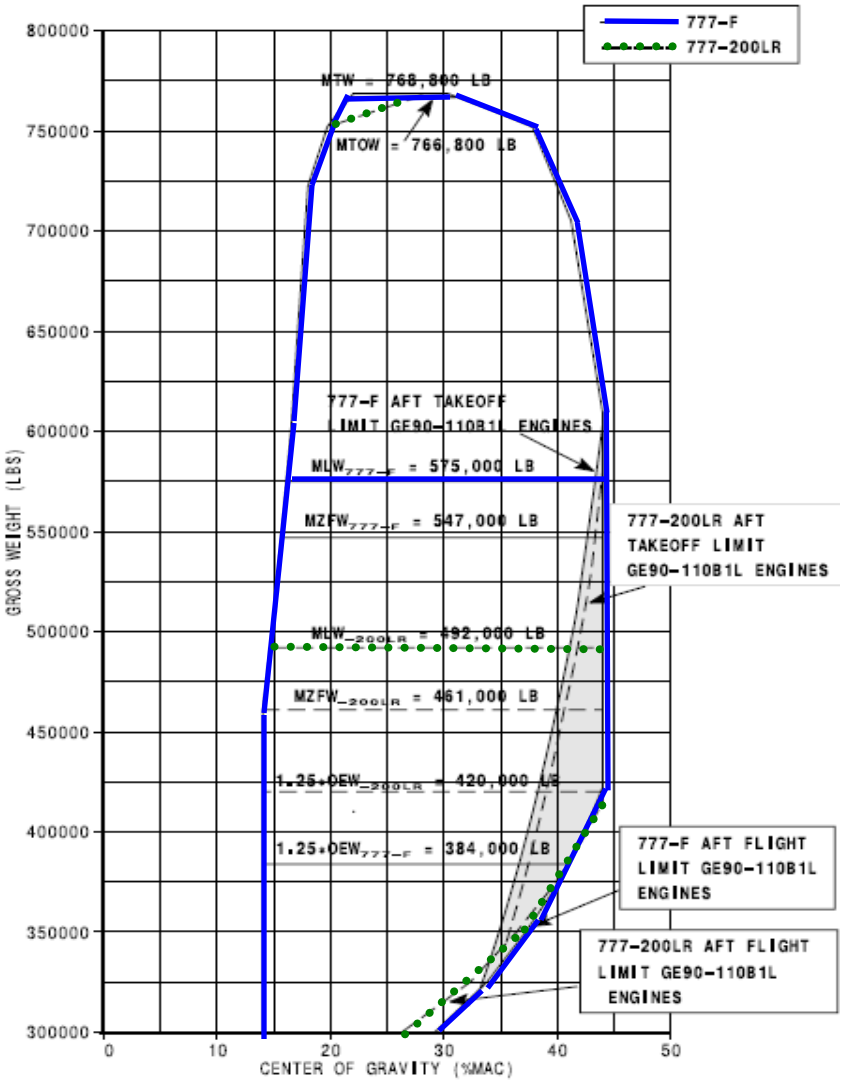
M_{LO} / M_{LE} = .82 ~ GEAR OPERATING MACH NUMBER

V_{FE}*	FLAP DETENT					
	1	5	15	20	25	30
777-F	265	245	230	225	200	180

*ALL FLAP PLACARDS, VCAS



777F Airplane Description
GW/CG Envelope

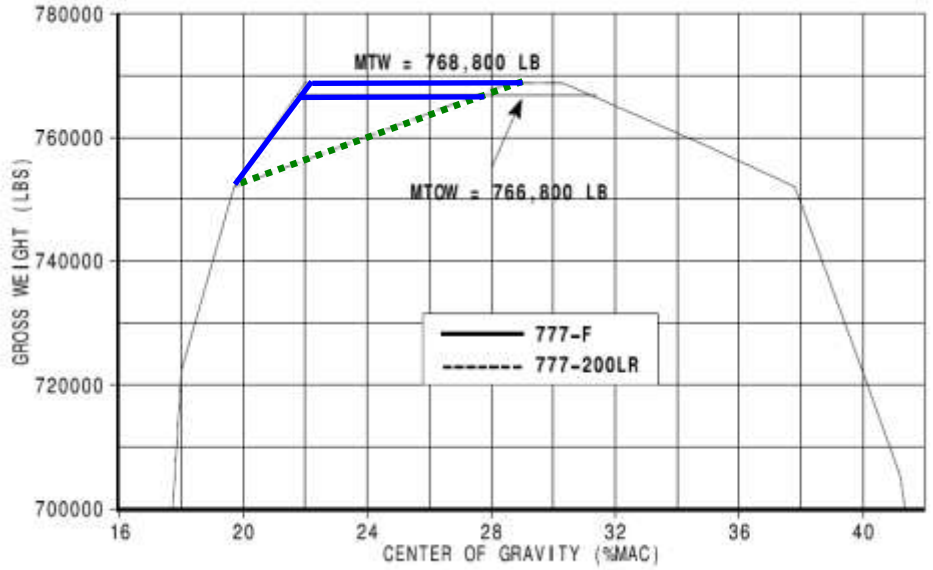


777F Airplane Description
Maneuver Load Alleviation

Maneuver Load Alleviation (MLA)

- **Purpose: Reduce wing bending loads due to positive maneuver conditions**
- **Function: Symmetrically deflects some lateral control surfaces as a function of normal load factor**
- **Benefit: Forward CG expansion without additional structure**
- **Application:**

  777F unique to-date.

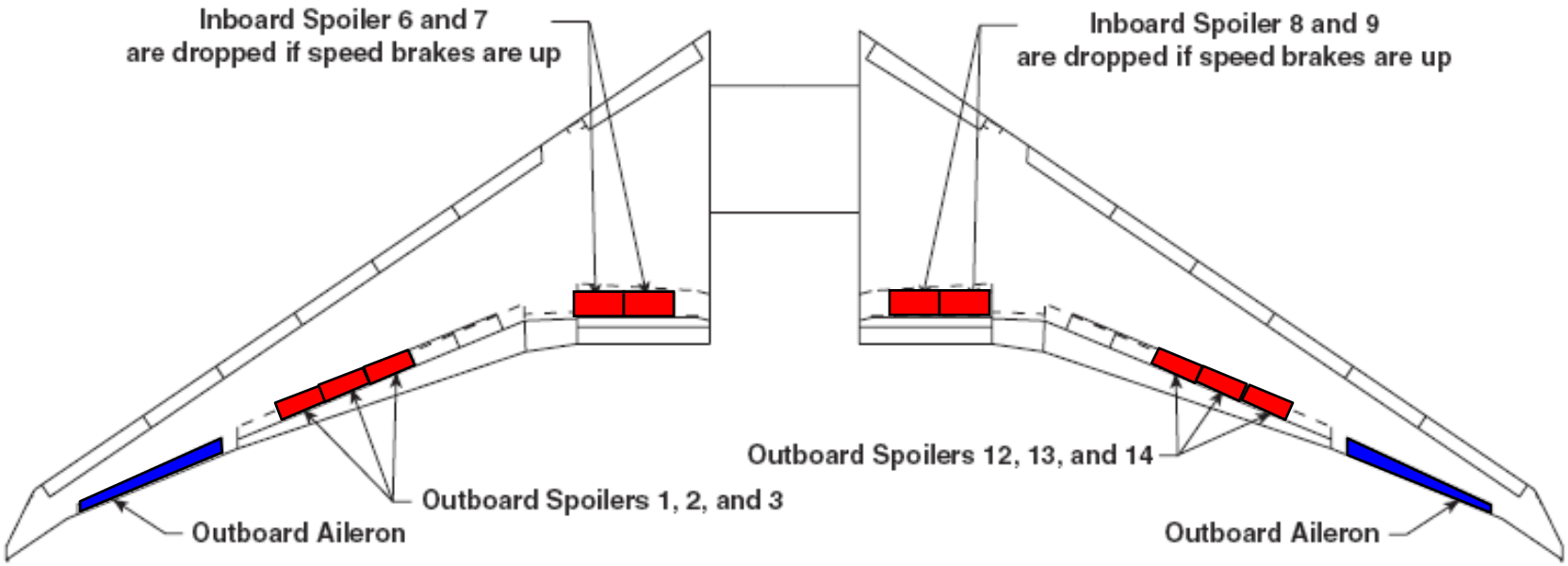


777F Airplane Description
MLA Details

Design Intent:

a) Handling Qualities unchanged during normal maneuvers

b) Handling Quality changes during elevated “g” maneuvers to be imperceptible



Agenda

- Introductions
- 777F airplane description/background
- Original flight test plans
- Aileron vibration discovery flights
- To fix or not to fix ?
- Re-test flights
- Lessons Learned
- Summary

Early Testing…

- **First Flight: July 14th, 2008**
  - Typical Boeing first flight profile - manual column, wheel, rudder kicks.
  - No MLA operation.
- **Second Flight: July 16th, 2008**
  - Completed conditions not performed on first flight required to commence planned test program
- **Modal Stability Flight Testing: July 26-29, 2008**
  - To evaluate interactions between MLA control law and airplane structure
  - First discovered aileron vibration on 3rd flight (7/26/2008)
- **MLA dedicated testing and all other planned testing (smoke, etc.)**
  - Put on hold until vibration issue could be discussed and/or fixed.

Agenda

- Introductions
- 777F airplane description/background
- Original flight test plans
- Aileron vibration discovery flights
- To fix or not to fix ?
- Re-test flights
- Lessons Learned
- Summary

Aileron vibration discovery flights

- **Flutter-type testing**
  - 2 altitudes and increasing Mach numbers
    - Manual controller “kicks”
    - Elevator frequency sweeps
    - Roller Coasters and “kicks” in turns (elevated g)

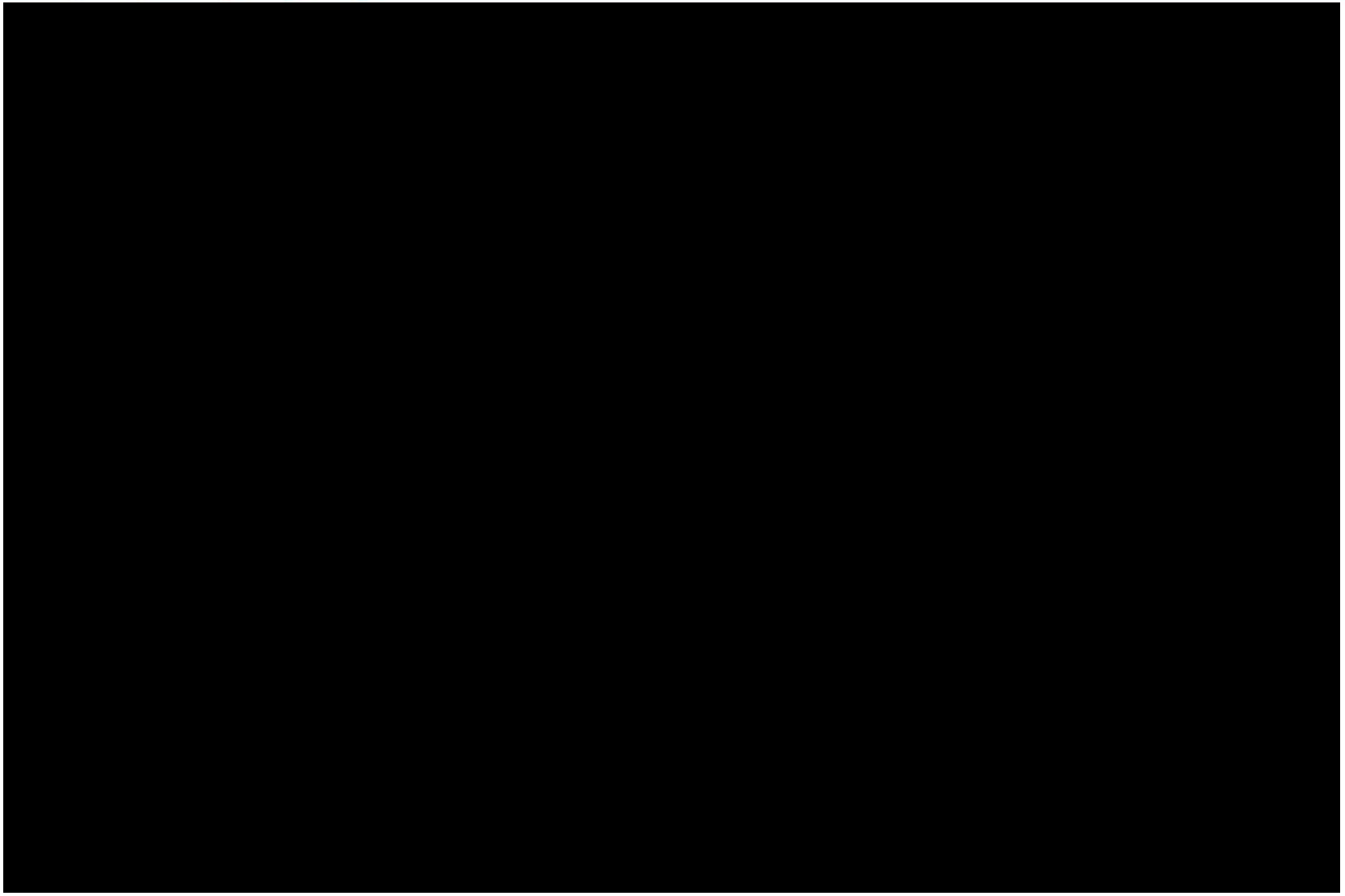
- **Aileron vibration occurred with trailing edge up deflections of ailerons.**
  - Ailerons had never been used previously at these speeds due to aileron lock-out function.
  - With additional MLA g bias applied (e.g.- PFC thinks it’s under a 1.8 G load): column kicks, shallow bank turns exhibited vibration
  - Without MLA g bias: 60 deg bank turns and roller coaster maneuvers to higher g levels showed vibration

Aileron Vibration Details

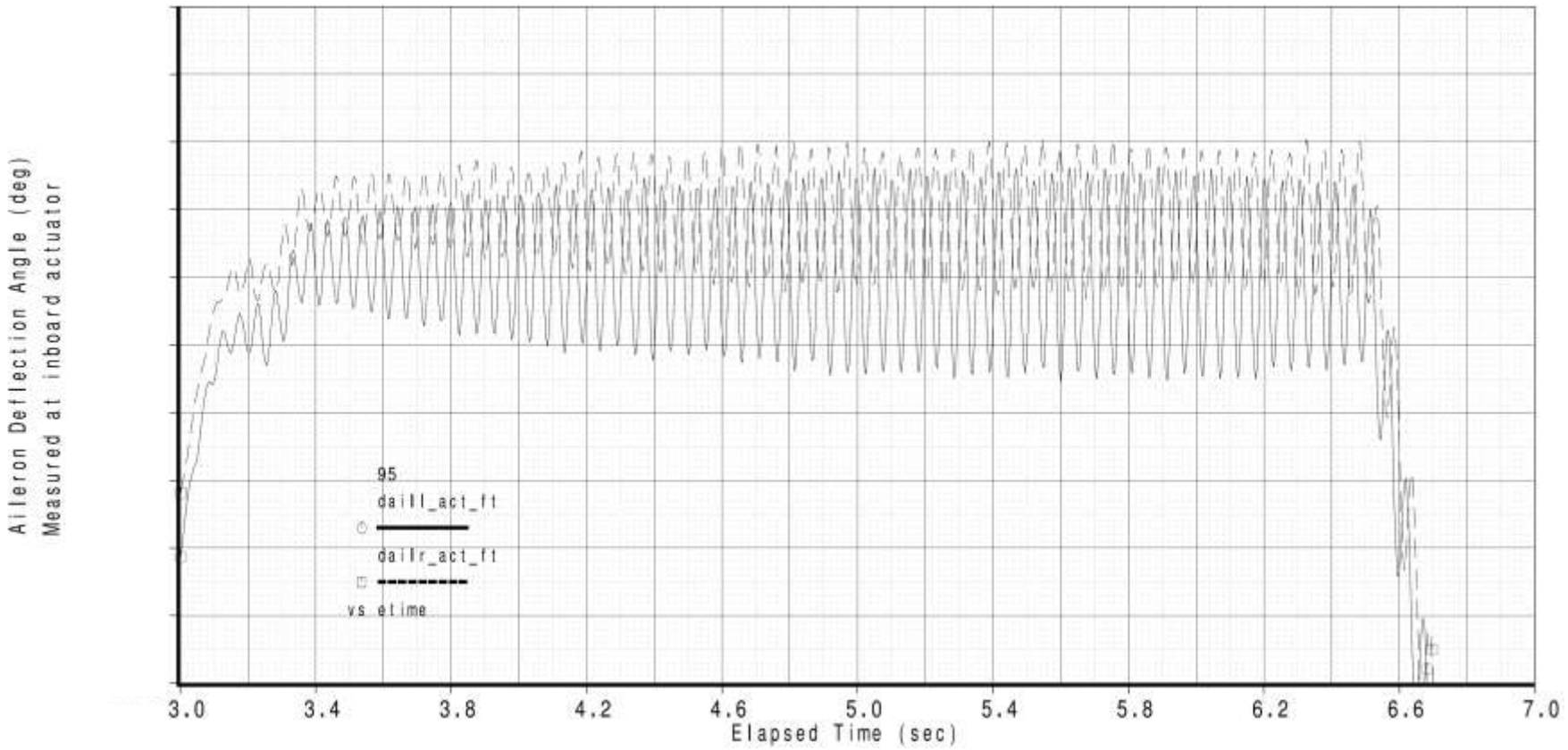
- **Pilot comments on Aileron Vibration:**
  - “Alarming.”
  - “Feels like driving over a washboard road.”
  - “Feels like something is going to come off.”
  - “Distracting and you naturally want to unload and slow down”

- **Causal factor unknown.**
  - Potential contributing factors include:
    1. Aileron deflection angle for vibration corresponds to approximately zero hinge moment
    2. A “scoop” is created between the mass balance tower and the lower surface of the wing when the aileron is deflected

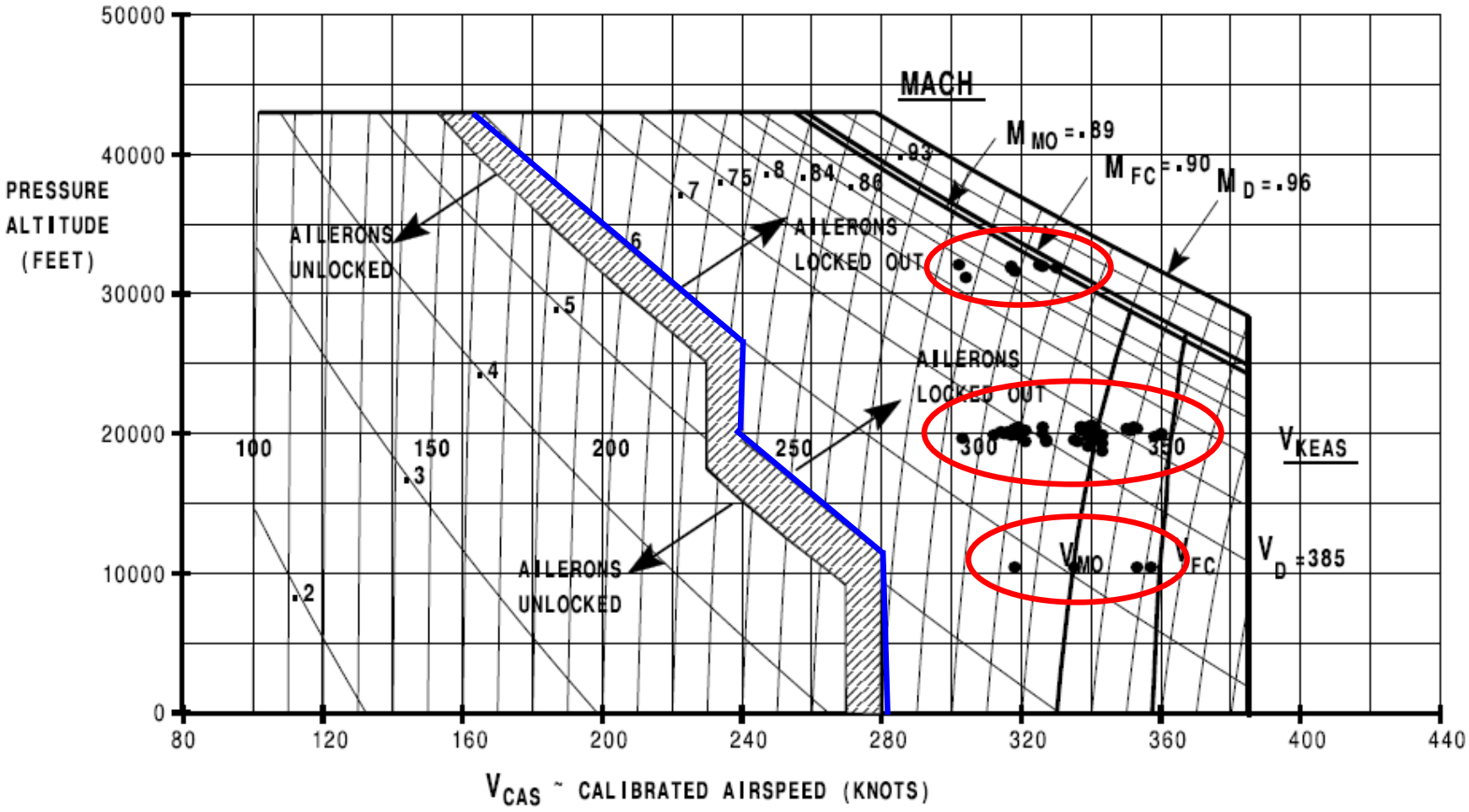
Aileron Vibration Video



Aileron Vibration Details



Aileron Vibration Mapping



777 Outboard Aileron Balance Tower

Agenda

- Introductions
- 777F airplane description/background
- Original flight test plans
- Aileron vibration discovery flights
- To fix or not to fix ?
- Re-test flights
- Lessons Learned
- Summary

To fix or not to fix ?

- **Likelihood of occurrence in service (1.9g event)**
  - Remotely encountered, if ever, in revenue service
- **Pilot opinion**
  - Needs to be fixed !
  - Avoidance maneuver consequences
  - Distracting (flight deck vibration cert issue)
- **Flutter concern**
  - No issue – mass balanced surface
- **Fatigue concern**
  - Further data required
- **Economics (Management opinion)**
  - Desire to not spend money because outside the “normal” envelope

Potential remedies

- **Aerodynamic modifications**
  - External wing treatments
  - Aerodynamic sealing
  - Internal flow diversion
- **Flight control software modifications**
  - Change to basic MLA aileron travel schedule
  - Addition of aileron “No-Dwell zone” function

Agenda

- Introductions
- 777F airplane description/background
- Original flight test plans
- Aileron vibration discovery flights
- To fix or not to fix ?
- Potential remedies
- Re-test flights
- Lessons Learned
- Summary

Re-test flights : Test Plan

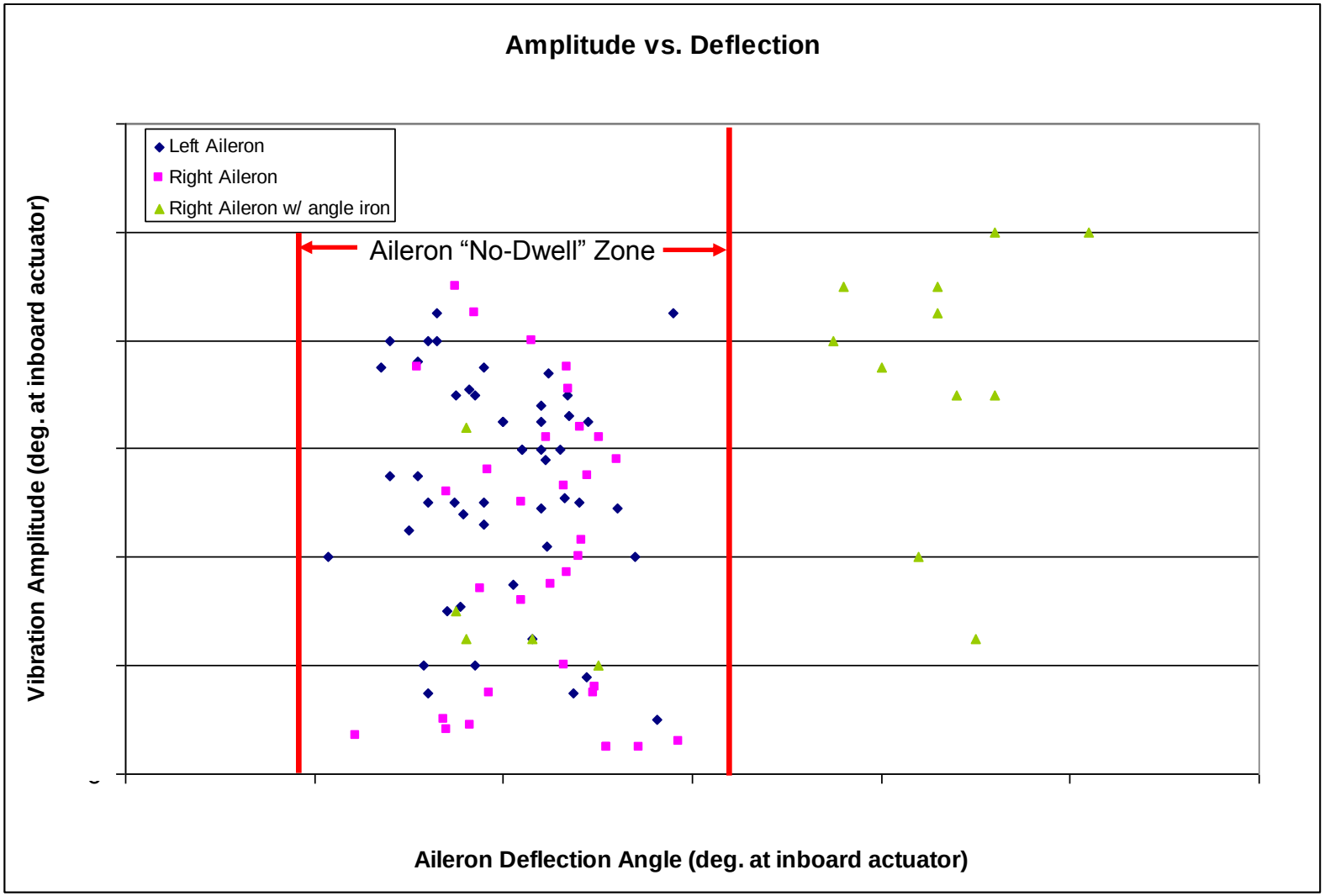
- **Flight test on August 6 with additional instrumentation and angle iron added**
  - Similar test conditions as before (kicks and turns)
  - Two altitudes (including one lower than previous)
  - Expected vibration and successfully repeated it

- **Flight test on August 18 with modified flight control law for MLA (aileron no-dwell zone functionality)**
  - Exclusively did shallow turns (with and without 0.8 g bias)
  - Tested with rollout configuration and with no-dwell active
  - Successfully eliminated vibration with no-dwell function

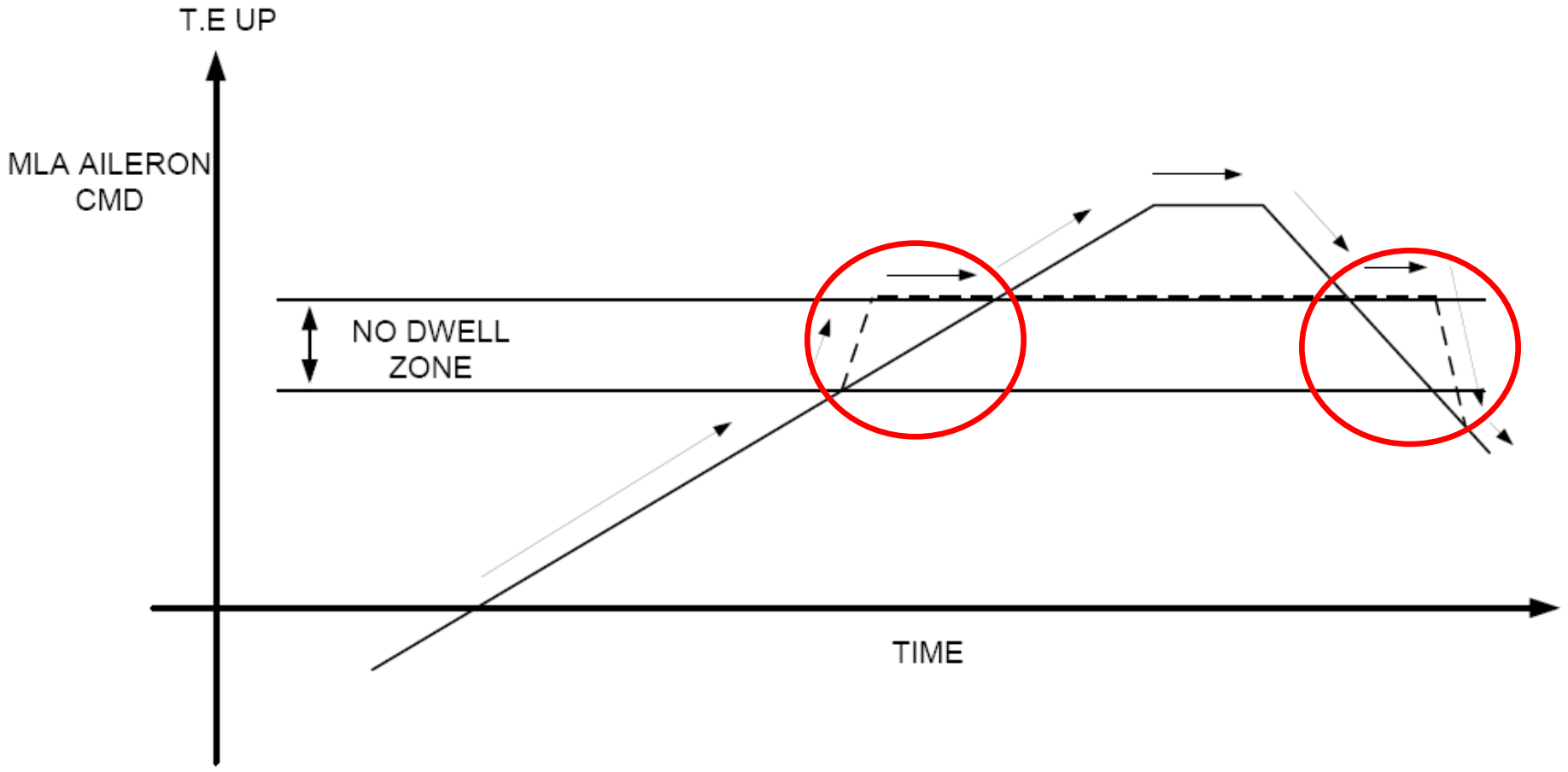
Re-test flights : Aileron Vibration Investigation

- **New Flight Test Parts/Instrumentation installed for:**
  - **Right Wing Aileron:**
    - Angle Iron attached in front of the outboard aileron balance tower.
    - Idea: Can we affect (not eliminate) the vibration by modifying local flow?
  - **Left Wing Aileron:**
    - Kulite pressure sensor to measure pressures in the cavity of balance tower
    - Strain gauge added to outboard aileron hinge for fatigue analysis
    - Accelerometer added to outboard trailing edge for loads analysis.

Re-test flights : Aileron Vibration Mapping



Re-test flights :
MLA Aileron “No Dwell” Zone



777F MLA Flight Testing (once vibration eliminated)

- **Steep Turns**
  - Determine if MLA interferes with pilot's ability to perform maneuver.
- **Rapid Elevator Inputs / Avoidance Maneuvers**
  - Ensure acceptable performance with MLA
- **Wind-Up Turns**
  - Flown at conditions where deterrent buffet would be >= 2.5 g's
- **Roller Coasters**
  - Evaluate handling qualities in pitch axis as MLA engages and disengages

Agenda

- Introductions
- 777F airplane description/background
- Original flight test plans
- Aileron vibration discovery flights
- To fix or not to fix ?
- Potential remedies
- Re-test flights
- Lessons Learned
- Summary

Lessons Learned

- **Fly-By-Wire airplane control laws present opportunities to remedy issues such as this**
- **Team approach to problem solving is required**
  - Especially when pilot opinion and engineering data differ
- **The “right thing” will still prevail once thorough communication occurs**
- **Important to capture lessons learned on specific technical “discoveries” to share between programs**
- **Pilot distraction needs to be considered as certification issue**

Agenda

- Introductions
- 777F airplane description/background
- Original flight test plans
- Aileron vibration discovery flights
- To fix or not to fix ?
- Potential remedies
- Re-test flights
- Lessons Learned
- Summary

Summary

Never assume that a test program will escape problems, no matter how seemingly "minor" the effort is !


Questions?

Flight Test Safety Workshop
27-30 April 2009
Ottawa, Ontario, Canada