Flight Test Safety Workshop
27-30 April 2009
Ottawa, Ontario, Canada
777 Freighter
Aileron Vibration Occurrence

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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
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777 Freighter First Flight
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
GW/CG Envelope

MTOW = 766,800 LB
MLW = 575,000 LB
MCLW = 547,000 LB
MLW = 392,000 LB
MCLW = 491,000 LB
1.25 MEW = 384,000 LB

777-200LR AFT TAKEOFF LIMIT GE90-110B1L ENGINES
777-200LR AFT FLIGHT LIMIT GE90-110B1L ENGINES
777-F AFT TAKEOFF LIMIT GE90-110B1L ENGINES
777-F AFT FLIGHT LIMIT GE90-110B1L ENGINES

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777F Aileron Vibration - FTSW 2009

9
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.
Design Intent:

a) Handling Qualities unchanged during normal maneuvers
b) Handling Quality changes during elevated “g” maneuvers
to be imperceptible
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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.
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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
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
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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
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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

Amplitude vs. Deflection

- Left Aileron
- Right Aileron
- Right Aileron with angle iron

Aileron "No-Dwell" Zone
Re-test flights:
MLA Aileron “No Dwell” Zone
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
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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
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Never assume that a test program will escape problems, no matter how seemingly “minor” the effort is!
Questions?
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