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Boundary Avoidance Tracking: How Avoiding An Accident Can Cause PIO

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Boundary Avoidance Tracking: How Avoiding An Accident Can Cause PIO

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C-17 Operational Test PIO

Summary

Scientia est Virtus

- Pilot induced oscillation (PIO) is normally thought of as a pilot overcontrolling while trying to maintain a condition (pitch, bank angle, etc.)
- Pilots also control to avoid a condition. This is boundary-avoidance tracking.
- PIOs may be the result of pilots attempting to avoid opposing boundaries.
- Pilots should be aware of how boundaries can drive dangerous control inputs.

What Causes PIO?

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TWO SITUATIONS (TASKS):

Walk a 12 inch stripe
across a parking lot

or

Walk a rigid 12 inch beam
between two skyscrapers

Physically, these are identical tasks!

- Why are they so different in practice?
- Why is the suspended task so hard?
- What does this have to do with flying airplanes?

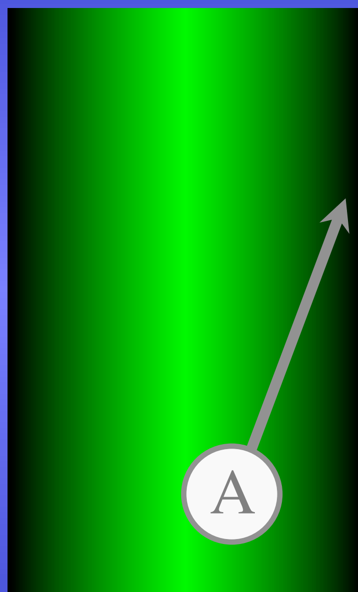
The Difference, in Summary

- Both have a traditional (and identical) tracking task--stay near the center of the beam.
- In the mind of the walker, the elevated task has *two additional tracking tasks*—

Do not go off either edge!

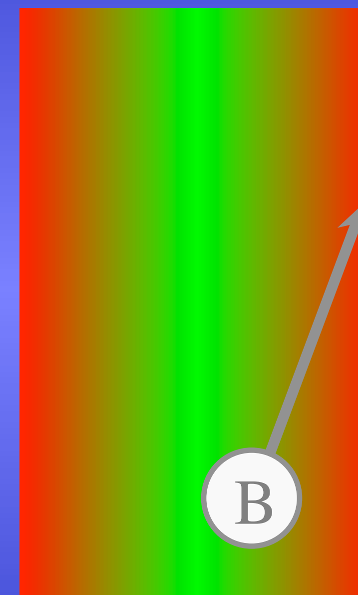
So What?

On The Ground



"Point Tracking"

Suspended



"Boundary-Avoidance Tracking"

Compare situations
A and B:

We humans respond very differently to B than to A.

The reason? We must avoid the boundary.

Point Tracking in an F-16

Boundary-Avoidance Tracking

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"Boundary-avoidance tracking" is tracking in relation to a boundary to prevent, or limit, exceeding that boundary

What can be a "Boundary?"

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- A physical barrier
  - The ground
  - Flight lead
  - The tanker
- A flight parameter
  - Aircraft g limits
  - Bank angle
- A boundary need not be safety critical
  - Evaluation performance criteria
  - Tracking performance criteria

Spectrum of Boundary Responses

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BOUNDARY TRACKING SPECTRUM

CONSEQUENCE OF EXCURSION:	MINOR TASK DISRUPTION	TASK FAILURE	LOSS OF LIFE OR AIRCRAFT
BOUNDARY TRACKING:	AVOIDANCE	AVOIDANCE	ESCAPE
BOUNDARY-TRACKING PILOT GAIN (K_{bm}):	MINIMAL	HIGH (MITIGATED)	MAXIMUM (UNMITIGATED)

Boundary-Escape Tracking

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“Boundary-Escape Tracking” is an extreme type of boundary tracking used when a boundary is perceived as an immediate threat to pilot or aircraft safety.

Boundary-Escape Tracking

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- Approach to a safety-critical boundary is perceived
- The pilot controls the aircraft to prevent contact with this boundary
  - The only goal is avoiding the boundary
  - All other tasks are momentarily forgotten
  - *Pilot gain may be driven by survival instinct*
  - *Overcorrection is instinctive*
  - *May trigger "fight/flight" response*
  - *May be a trigger for point-tracking PIO*

Only one “boundary” at a time is experienced. In this case, the cat fixates on a threat near the camera.

Boundary-Escape PIO Examples

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- A common automobile oscillation
  - Tasks: Don’t go off the road/don’t go in the opposite lane!
- T-38 solo student PIO during a wing approach
  - Tasks: Don’t hit the ground, don’t lose sight of your lead aircraft!
- KC-135 pilot during a crosswind landing
  - Tasks: Don’t cause a pod strike!

Boundary-Driven PIO between the runway and stall/departure?

Early V-22 Production Acceptance Flight

YF-22 Low Approach

Modeling Boundary-Avoidance Tracking

Modeling Boundary Tracking

- The pilot's response (control input) is determined by the instantaneous time to the boundary
- Parameters:
  - Latency (delay in the pilot's response)
  - Time to the boundary for minimum response
  - Time to the boundary for maximum response
  - Magnitude of maximum response

Simulator Data, Example 1

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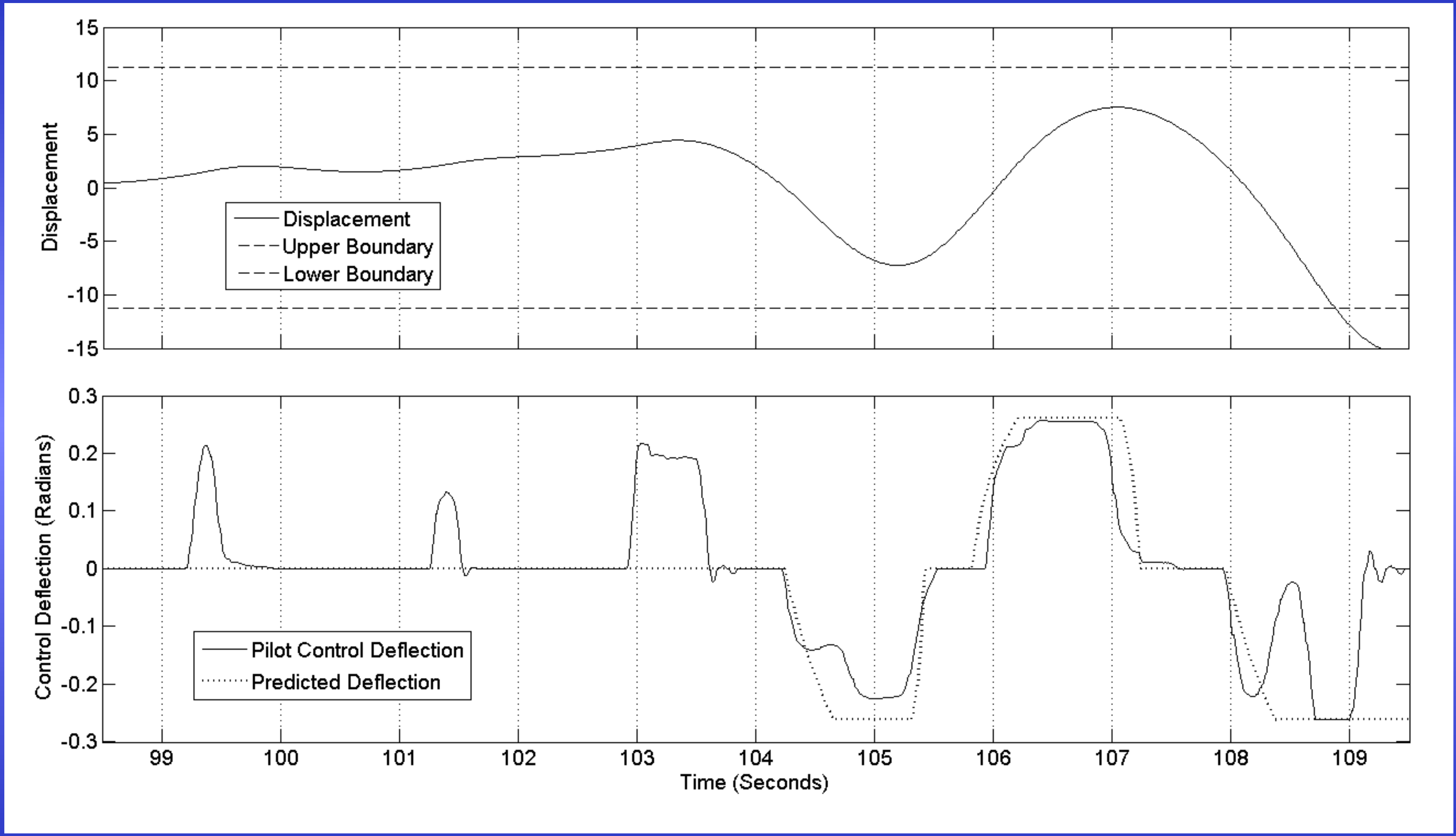

Subject H1, K_{bm}: 0.26 rad (max avail.), τ_b: 300 ms, t_{min}: 2.1 sec, t_{max}: 1 sec

Simulator Data, Example 2

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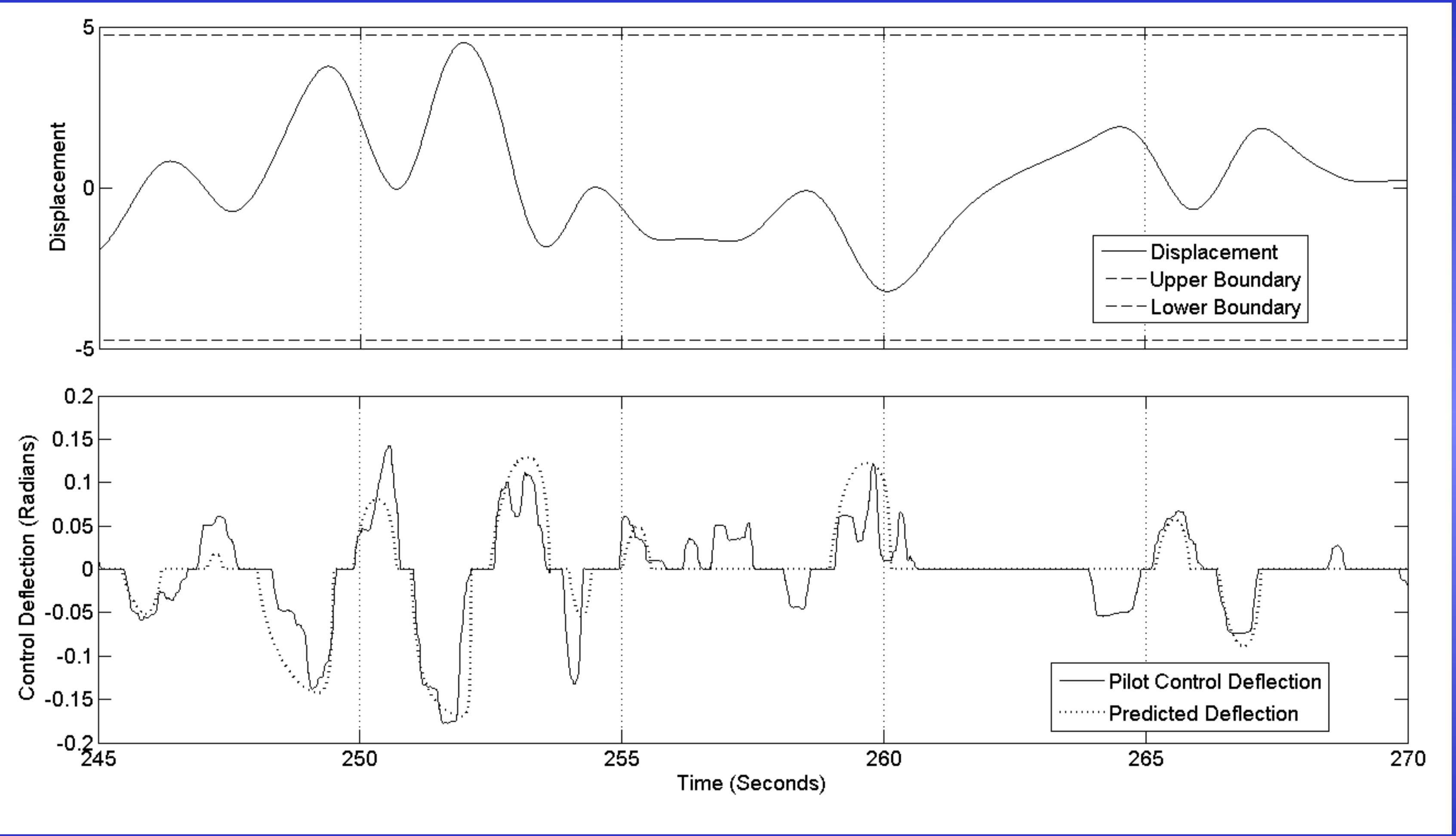

Subject F2, K_{bm}: 0.17 rad (65% of max avail.), τ_b: 150 ms, t_{min}: 2.5 sec, t_{max}: 0.2 sec

Modeling Results

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- Boundary-escape tracking between opposing boundaries could cause severe oscillations in an otherwise stable system
  – Resulted in bang-bang control inputs
  – Inputs rapidly grew to maximum
  – Extremely non-linear (“cliffy”) results
  – Increased lag was a powerful driver of PIO

Implications for FQ Prediction

- Can we learn how humans perceive boundaries and what it takes to cause a boundary tracking response?
  - What data is "out there?"
  - How do we get more?
- Can we use this information to predict where boundary-driven PIO might be a hazard?
  - Pitch acceleration/rate in ground effect
  - Altitude response delays in formation
- *Can awareness of this phenomenon aid PIO prevention?*

Conclusions

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- PIO may be caused by either "point tracking" a parameter or "boundary tracking" between opposite boundaries
- Boundary-avoidance tracking can create PIO
- Boundary-escape tracking produces especially hazardous PIO

The ability to recognize boundary-avoidance tracking may aid PIO prevention, recognition, and recovery

Summary

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- Pilot induced oscillation (PIO) is normally thought of as a pilot overcontrolling while trying to maintain a condition (pitch, bank angle, etc.)
- PIOs may be the result of pilots attempting to avoid opposing limits, or "boundaries." This is boundary-avoidance tracking (BAT).
- Boundary-escape tracking is a particularly dangerous type of BAT where the boundary is hazardous.
- Pilots should be aware of how boundaries can drive dangerous control inputs.