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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Summary

- 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?

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!
On The Ground

A

A and B:
We humans respond very differently to B than to A.
The reason? We must avoid the boundary.

Suspended

B

“Point Tracking”

“Boundary-Avoidance Tracking”
Point Tracking in an F-16
“Boundary-avoidance tracking” is tracking in relation to a boundary to prevent, or limit, exceeding that boundary
What can be a “Boundary”?

• 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

<table>
<thead>
<tr>
<th>CONSEQUENCE OF EXCURSION:</th>
<th>MINOR TASK DISRUPTION</th>
<th>TASK FAILURE</th>
<th>LOSS OF LIFE OR AIRCRAFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOUNDARY TRACKING:</td>
<td>AVOIDANCE</td>
<td>AVOIDANCE</td>
<td>ESCAPE</td>
</tr>
<tr>
<td>BOUNDARY-TRACKING PILOT GAIN ($K_{bm}$):</td>
<td>MINIMAL</td>
<td>HIGH (MITIGATED)</td>
<td>MAXIMUM (UNMITIGATED)</td>
</tr>
</tbody>
</table>
“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

- 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

• 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
Subject H1, $K_{bm}$: 0.26 rad (max avail.), $\tau_b$: 300 ms, $t_{min}$: 2.1 sec, $t_{max}$: 1 sec
Simulator Data, Example 2

Subject F2, $K_{bm} : 0.17 \text{ rad (65\% of max avail.)}, \tau_b : 150 \text{ ms}, t_{min} : 2.5 \text{ sec}, t_{max} : 0.2 \text{ sec}
Modeling Results

• 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

• 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

- 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.