Objective Motion Cueing Criteria for Commercial Transport Simulators

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This paper adds data to establish fidelity criteria for the simulator motion system diagnostic test now required during commercial aircraft simulator approval in the United States. Nineteen airline transport pilots flew three tasks under six different motion conditions in an experiment on the NASA Vertical Motion Simulator. The motion conditions allowed refinement of the initial fidelity criteria developed in previous experiments. In line with these previous experiments, the motion condition significantly affected (1) false motion cue pilot ratings, and sink rate and longitudinal deviation at touchdown in the approach and landing task, (2) false motion cue pilot ratings, roll deviations, and maximum pitch rate in the stall task, and (3) false motion cue pilot ratings, heading deviation, and pedal reaction time after an engine failure in the take-off task. Combining data from three experiments, significant differences in pilot-vehicle performance were used to define objective motion cueing criteria boundaries. These fidelity boundaries suggest that some hexapod simulators can possibly produce motion cues with improved fidelity in several degrees of freedom.
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Outline

Introduction
Tasks
Motion Conditions
Experiment design
Results
Conclusions
Introduction

Previously, during a simulator qualification:
• Engineers measured motion hardware
• Pilot inspectors assessed hardware + software

Now:
• FAA part 60 requires an Objective Motion Cueing Test (OMCT) for new devices
  – Currently, no fidelity criteria accompany the test
Introduction

Objective Motion Cueing Test

- aircraft model
- pilot station
- accelerations

motion logic software

motion system hardware

simulator
- pilot station
- accelerations

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Roll magnitude

- magnitude
- frequency, rad/s

Roll phase

- phase, deg
- frequency, rad/s

mean of 8 devices

±2 sigma of 8 devices
Introduction

Objective Motion Cueing Test

- Aircraft model
- Pilot station accelerations
- Motion logic software
- Motion system hardware
- Simulator
- Pilot station accelerations

Roll magnitude vs. frequency, rad/s
- Adequate
- Inadequate

Roll phase vs. frequency, rad/s
- Adequate
- Inadequate
Introduction

Objective:

Develop fidelity criteria for the Objective Motion Cueing Test for Commercial Transport Simulators

What’s new?

- Well-behaved transport aircraft
- Three tasks, 6 new motion configurations
- World’s largest motion simulator
- Sufficiently large pilot pool
Tasks

1. Approach and landing with sidestep
2. High-altitude stall recovery
3. Engine out on takeoff
Motion Conditions

Six motion configurations per task:
1. Gain/break-frequency tradeoff
2. Compare degrees of freedom
3. False tilt motion cues
Motion Conditions

• Sidestep task:
  1. Surge motion -> Tail windshear recovery
  2. Roll motion -> Perceived tilt cues in turns
  3. Pitch and heave -> Landing flare

• Stall task:
  1. Roll motion -> Roll disturbance compensation
  2. Roll motion -> Perceived tilt cues in turn
  3. Pitch and heave -> Secondary stall occurrence

• Takeoff task:
  1. Surge to pitch -> Perceived tilt cues initial acc.
  2. Yaw and sway -> Engine failure compensation
Motion Conditions

Pitch magnitude

Heave magnitude

Sway to roll magnitude
Experiment Design

• 19 airline transport pilots
• Three challenging flight tasks
• Six motion configurations per task
• Six repetitions per task and motion configuration

• B757-like aircraft model
• Cockpit: side-by-side with B777-like primary display
Experiment Design

• Dependent measures:
  – Three subjective ratings of false tilt motion
  – 12 objective task-performance measures
Performance Results
Sidestep Task

Sinkrate at Touchdown, ft/s

Decreasing heave gain and increasing break frequency
Performance Results
High-Altitude Stall

Roll deviation RMS, deg

Max pitch rate, deg

Decreasing roll break frequency
Decreasing heave fidelity and increasing pitch fidelity
Performance Results
Takeoff Task

Heading deviation RMS, deg

Pedal response time, s

Increasing sway fidelity and decreasing yaw fidelity
Motion Rating Results
Sidestep Task

Maximum lateral tilt cue, \( \text{ft/s}^2 \)

False motion cue rating, %

0.1 g perceptual threshold

Increasing false lateral specific force cues
Motion Rating Results
Takeoff Task

Max tilt-coordination pitch rate, deg/s

False motion cue rating, %

3 deg/s perceptual threshold

Increasing false pitch rate cues
Results

Objective Motion Cueing Criteria

Step 1: Touchdown sinkrate, ft/s

Step 2: Heave uncertainty bounds

statistically different
Results

Objective Motion Cueing Criteria

Step 3:
Heave response fit

Step 4:
Heave fidelity region
Rotational Motion Cueing Bounds

Pitch

Roll

Yaw

magnitude

magnitude

magnitude

phase, deg

phase, deg

phase, deg

frequency, rad/s

frequency, rad/s

frequency, rad/s
Translational Motion Cueing Bounds

Surge

Sway

Heave

magnitude

magnitude

magnitude

phase, deg

phase, deg

phase, deg

frequency, rad/s

frequency, rad/s

frequency, rad/s
Cross-Coupling Bounds

Roll to sway

Surge to pitch

magnitude

phase, deg

frequency, rad/s

frequency, rad/s
Conclusions

1. Motion condition significantly affected:
   - Sinkrate at touchdown in the landing
   - Roll deviation in the stall approach
   - Maximum pitch rate in the stall recovery
   - Heading deviation after the engine failure
   - Pedal reaction time after the engine failure

2. False motion cues above the perceptual threshold resulted in higher false motion cue ratings in all tasks
Conclusions

3. Significant differences between motion configurations defined initial objective motion cueing criteria

4. Initial comparison against data from one simulator manufacturer shows promise. Translational motion fidelity would need improvement
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