Objective Motion Cueing Criteria for Commercial Transport Simulators

Peter M. T. Zaal, San Jose State University; Jeffery A. Schroeder, Federal Aviation Administration; William W. Chung, Science Applications Internatinoal Corporation

This paper adds data to establish fidelity criteria for the simulator motion system diagnostic test now re- quired 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 Simula- tor. 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 mo- tion 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 mo- tion 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

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Experiment design

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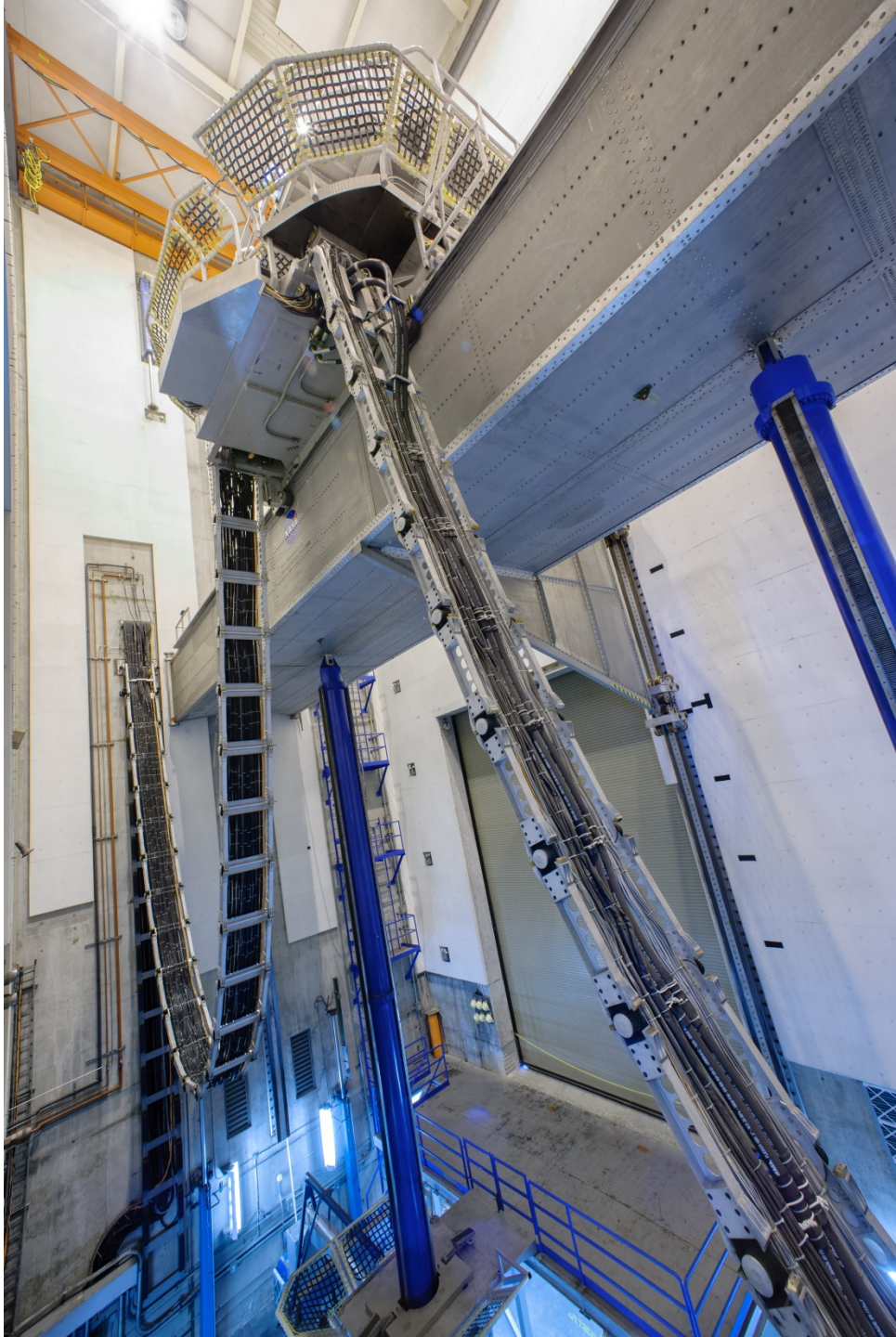


Introduction

Previously, during a simulator qualification:

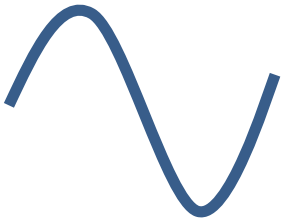
- Engineers measured motion hardware
- Pilot inspectors assessed hardware + software

Now:

- FAA part 60 requires an Objective Motion Cueing Test (OMCT) for new devices
  - Currently, no fidelity criteria accompany the test

Introduction

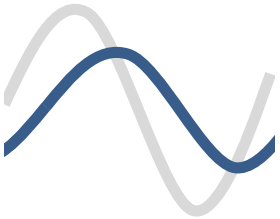
Objective Motion Cueing Test



aircraft model
pilot station
accelerations

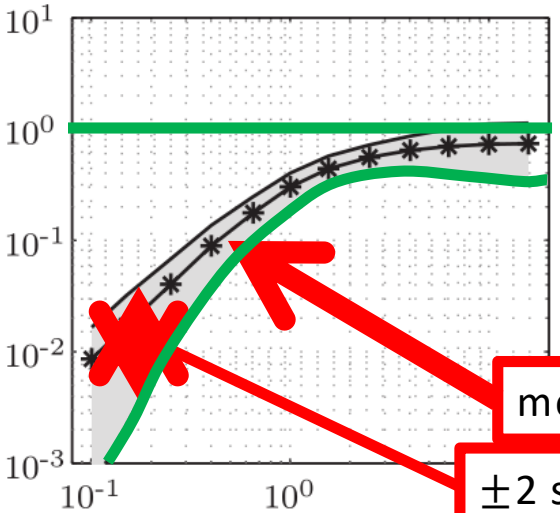
motion logic
software

motion system
hardware

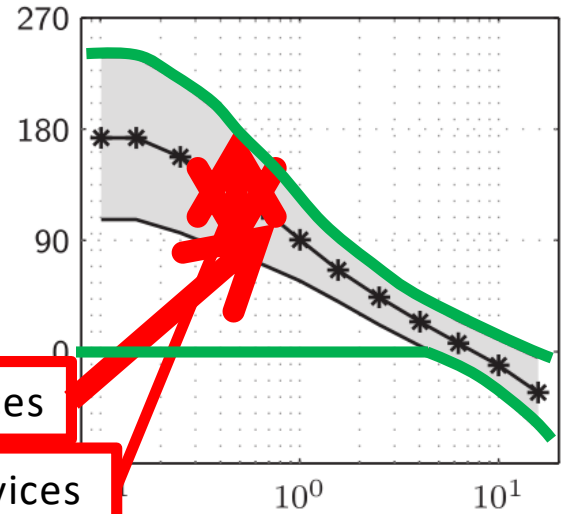


simulator
pilot station
accelerations

Roll magnitude



Roll phase

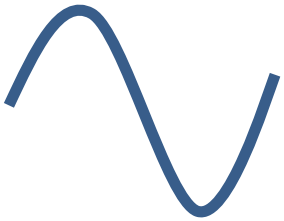


mean of 8 devices

±2 sigma of 8 devices

Introduction

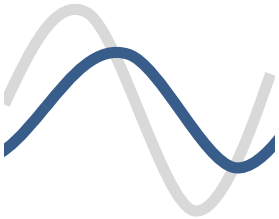
Objective Motion Cueing Test



aircraft model
pilot station
accelerations

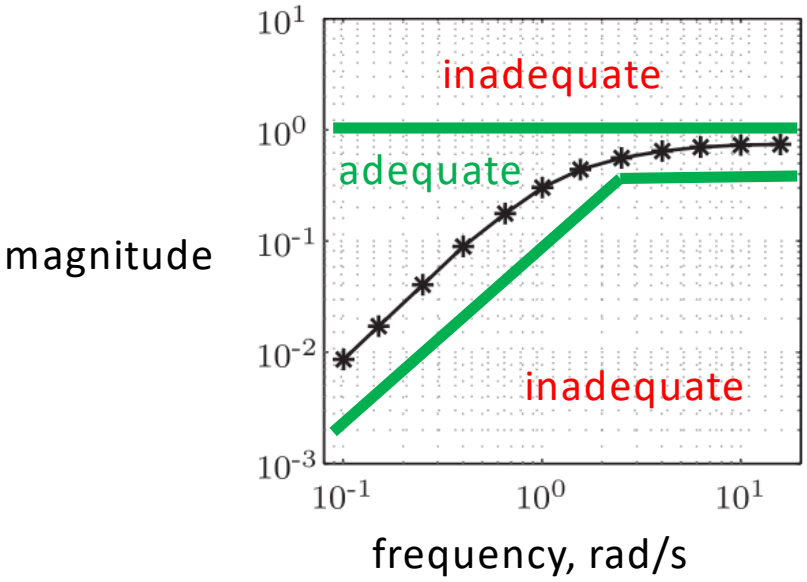
motion logic
software

motion system
hardware

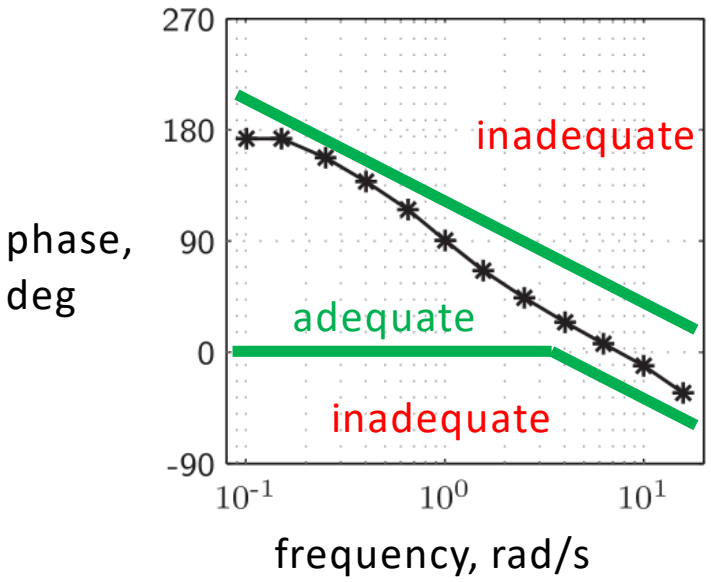


simulator
pilot station
accelerations

Roll magnitude



Roll phase



Introduction

Objective:

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

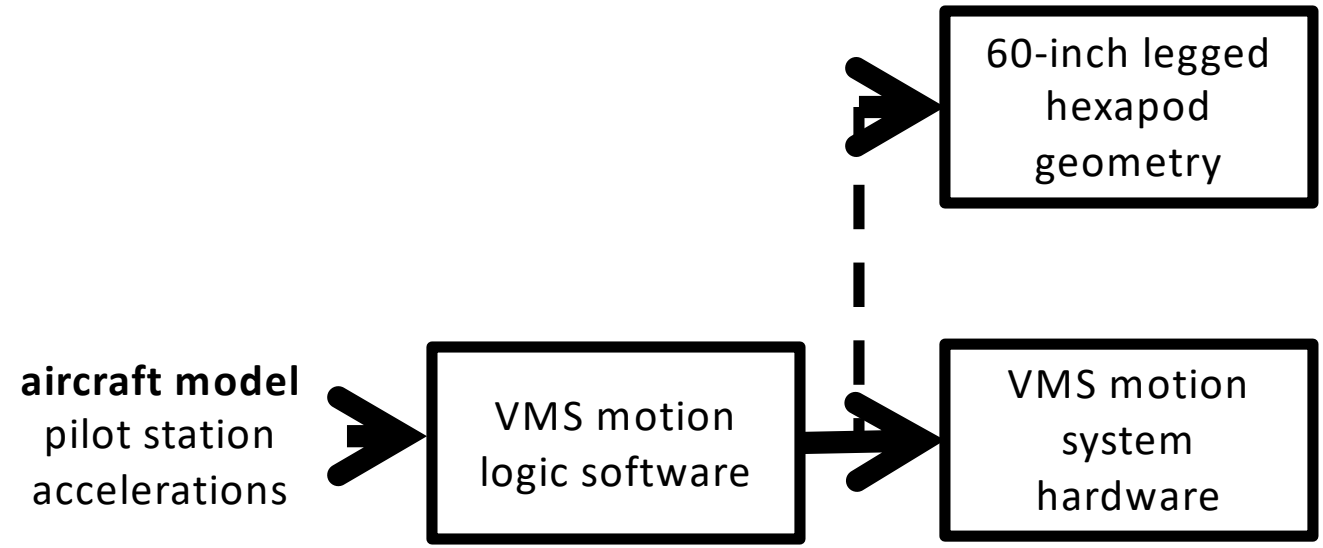
What's new?

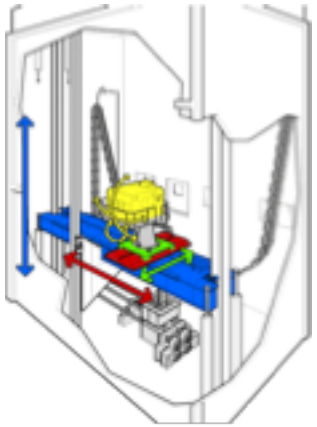
- Well-behaved transport aircraft
- Three tasks, 6 new motion configurations
- World's largest motion simulator
- Sufficiently large pilot pool

Tasks

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

Motion Conditions





Six motion configurations per task:

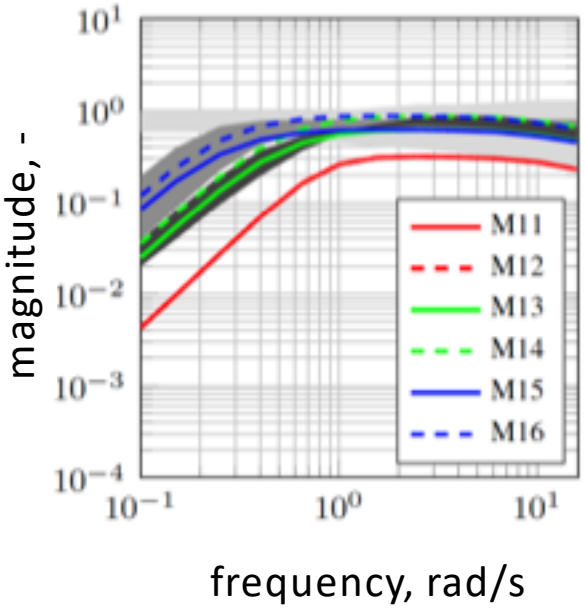
1. Gain/break-frequency tradeoff
2. Compare degrees of freedom
3. False tilt motion cues

Motion Conditions

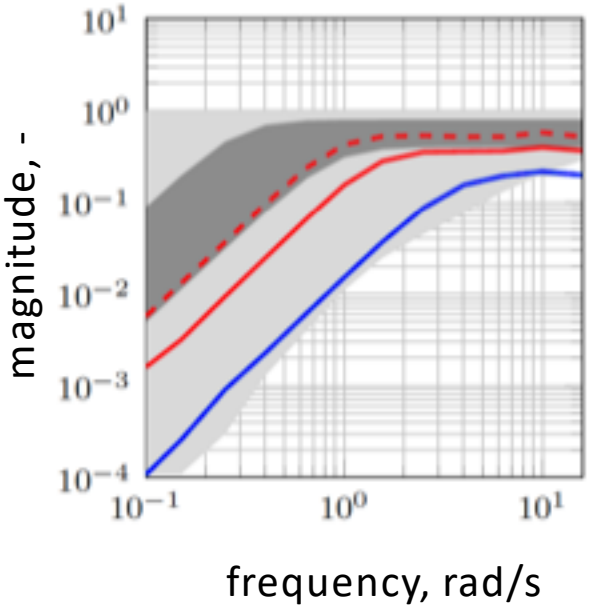
- Sidestep task:
  1. Surge motion -> Tail windshear recovery
  2. Roll motion -> Perceived tilt cues in turns
  3. Pitch and heave -> Landing flare
- Stall task:
  1. Roll motion -> Roll disturbance compensation
  2. Roll motion -> Perceived tilt cues in turn
  3. Pitch and heave -> Secondary stall occurrence
- Takeoff task:
  1. Surge to pitch -> Perceived tilt cues initial acc.
  2. Yaw and sway -> Engine failure compensation

Motion Conditions

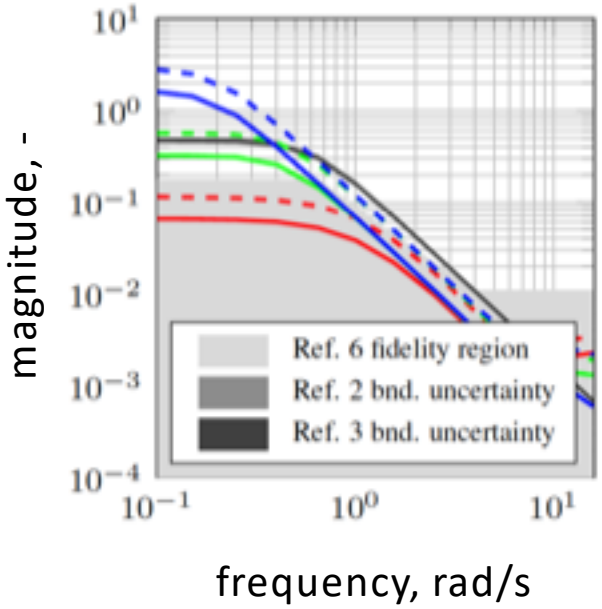
Pitch magnitude



Heave magnitude



Sway to roll magnitude



Full
VMS
Motion

High
Gain
Hexapod

Low
Gain
Hexapod

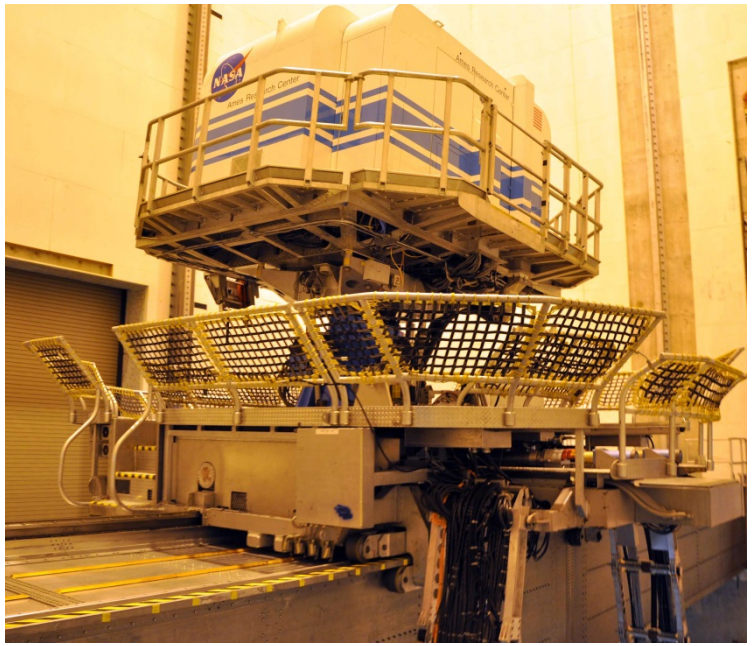
Experiment Design

- 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

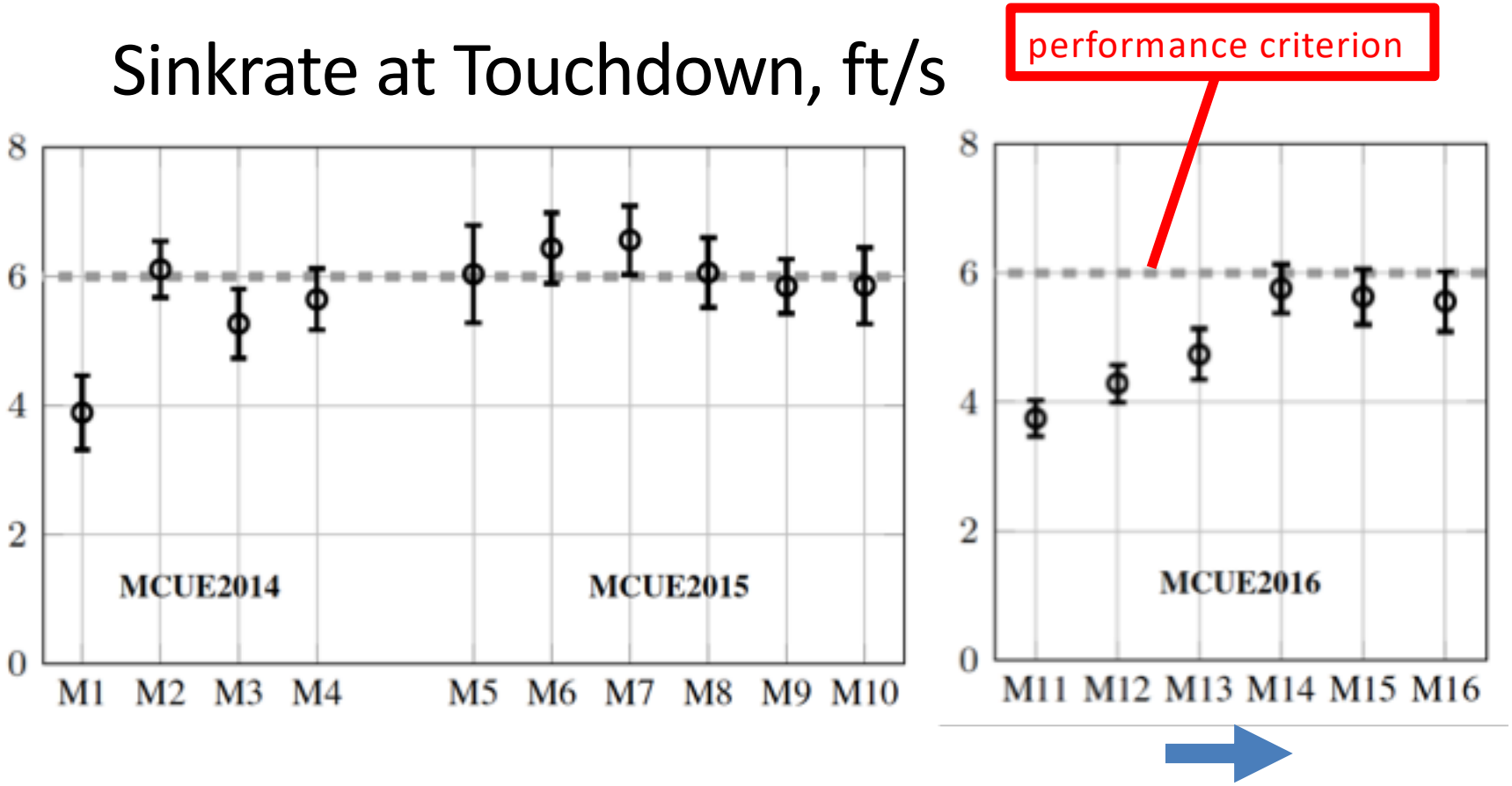
Experiment Design

- Dependent measures:
  - Three subjective ratings of false tilt motion
  - 12 objective task-performance measures



Performance Results
Sidestep Task

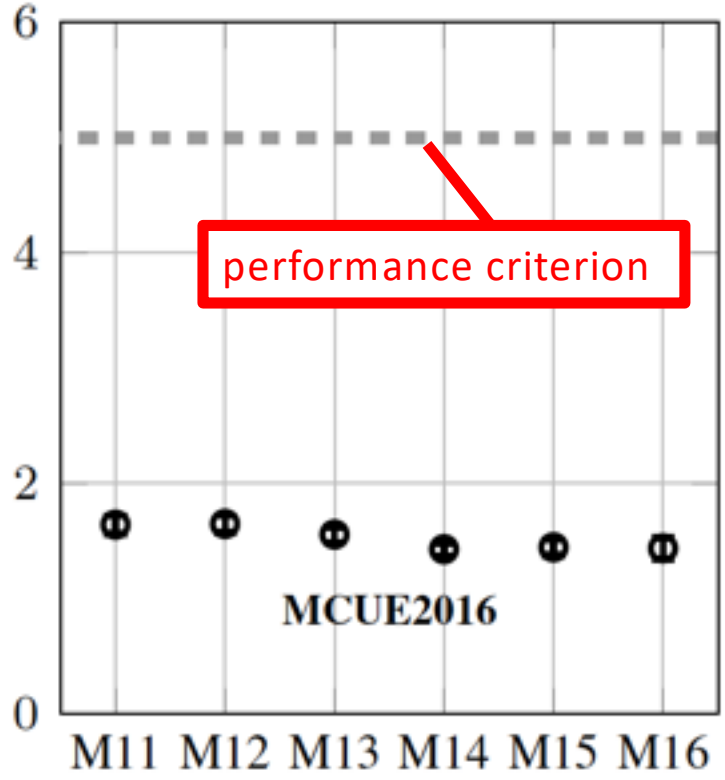
Sinkrate at Touchdown, ft/s



Decreasing heave gain and increasing break frequency

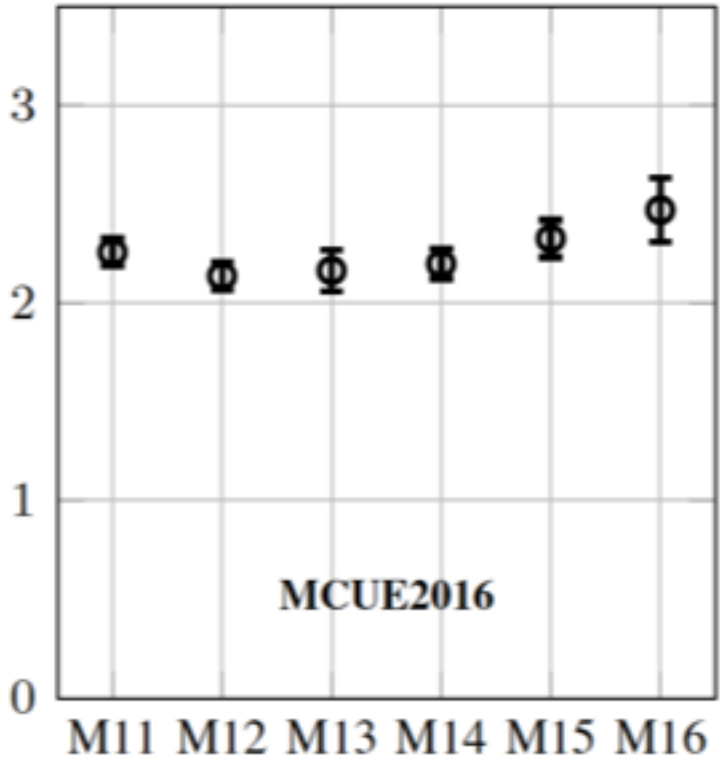
Performance Results
High-Altitude Stall

Roll deviation RMS, deg



Decreasing roll break frequency

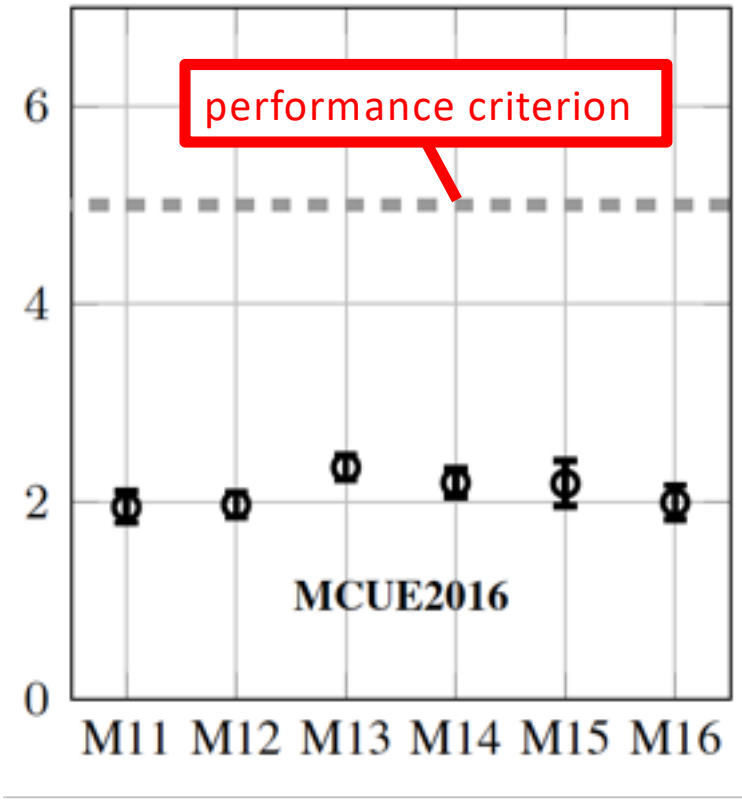
Max pitch rate, deg



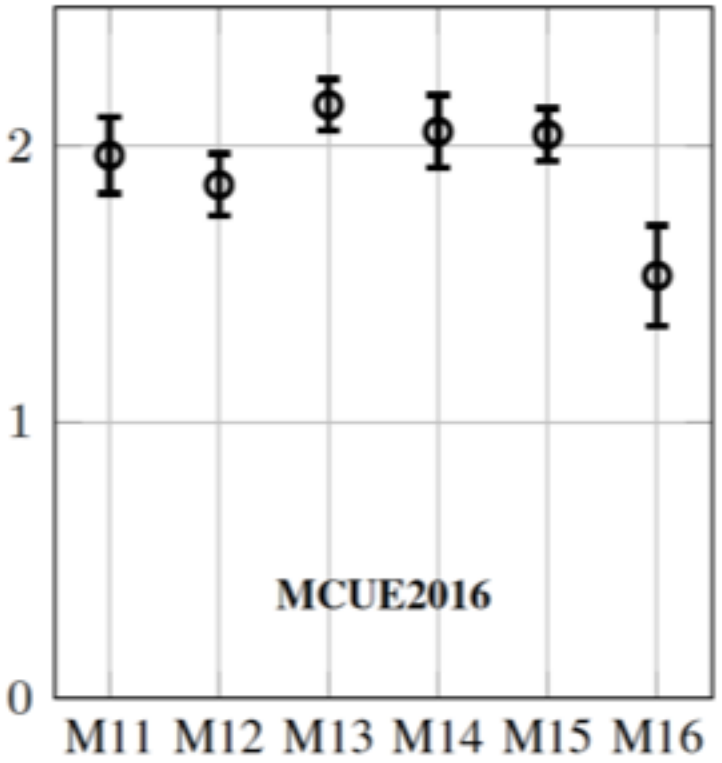
Decreasing heave fidelity and increasing pitch fidelity

Performance Results
Takeoff Task

Heading deviation RMS, deg



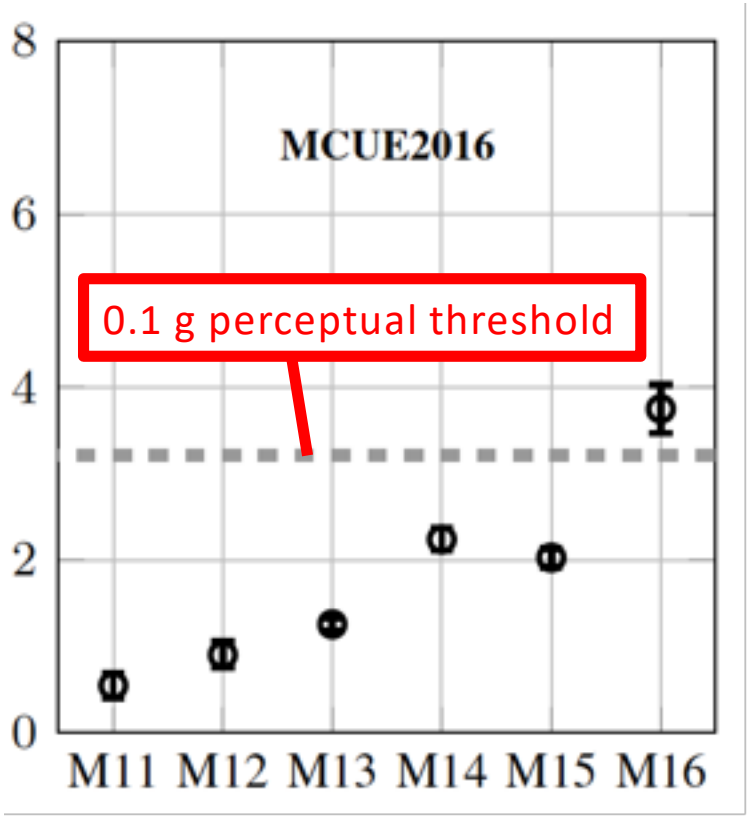
Pedal response time, s



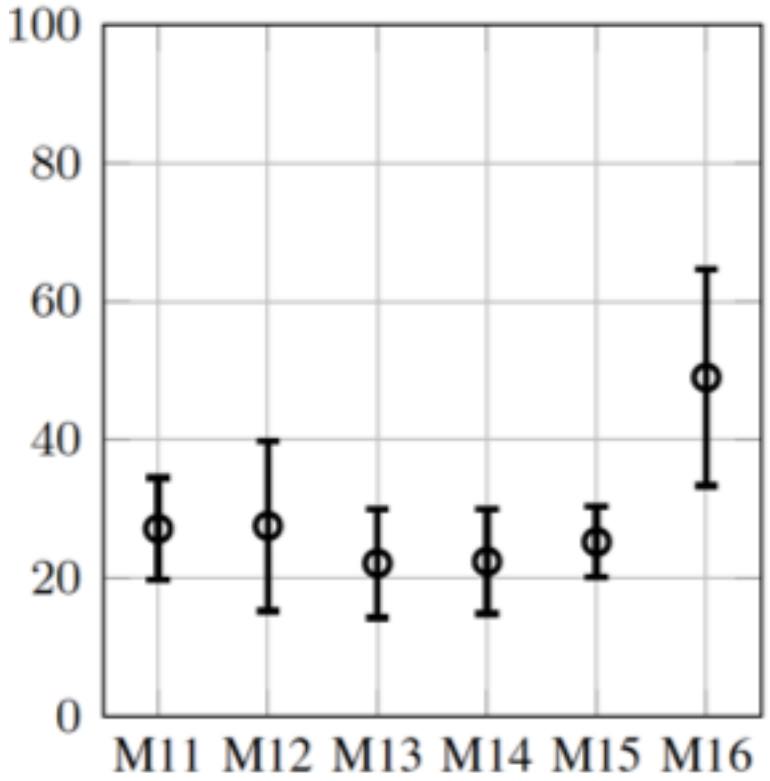
Increasing sway fidelity and decreasing yaw fidelity

Motion Rating Results
Sidestep Task

Maximum lateral tilt cue, ft/s^2



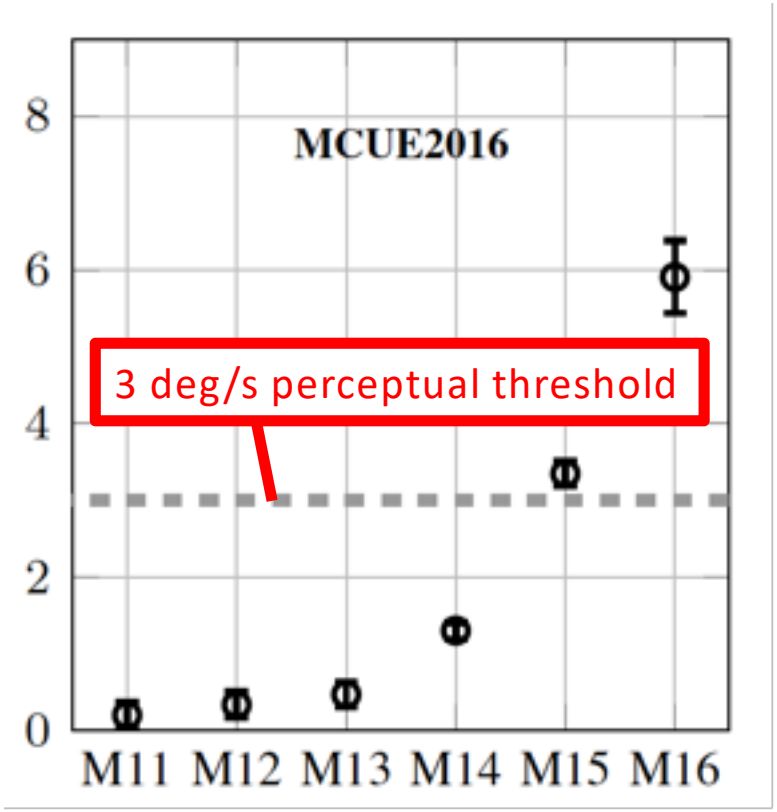
False motion cue rating, %



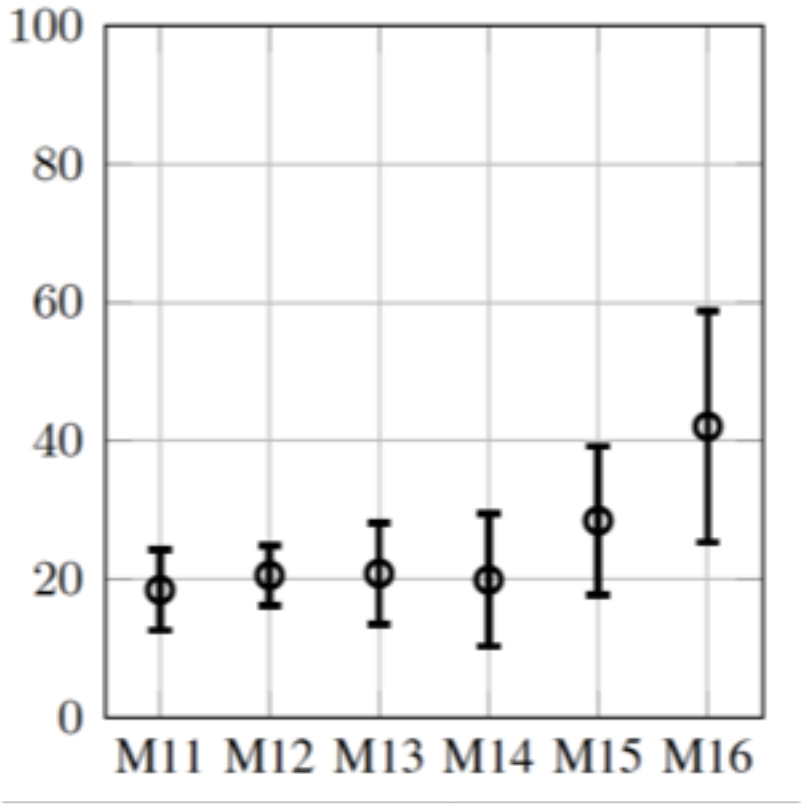
Increasing false lateral specific force cues

Motion Rating Results
Takeoff Task

Max tilt-coordination pitch rate, deg/s



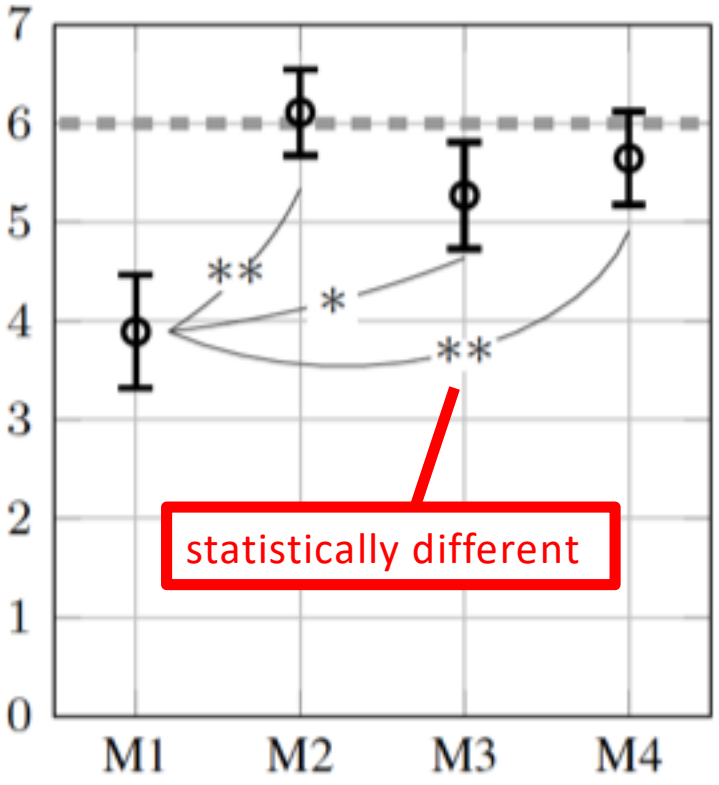
False motion cue rating, %



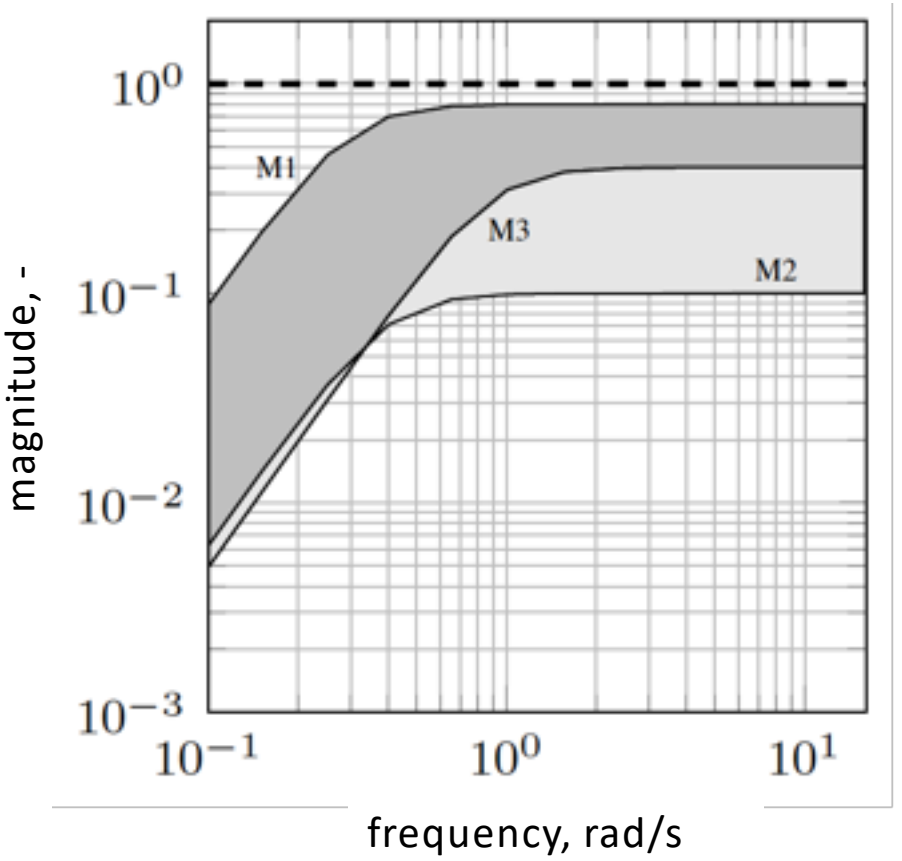
Increasing false pitch rate cues

Results
Objective Motion Cueing Criteria

Step 1:
Touchdown sinkrate, ft/s

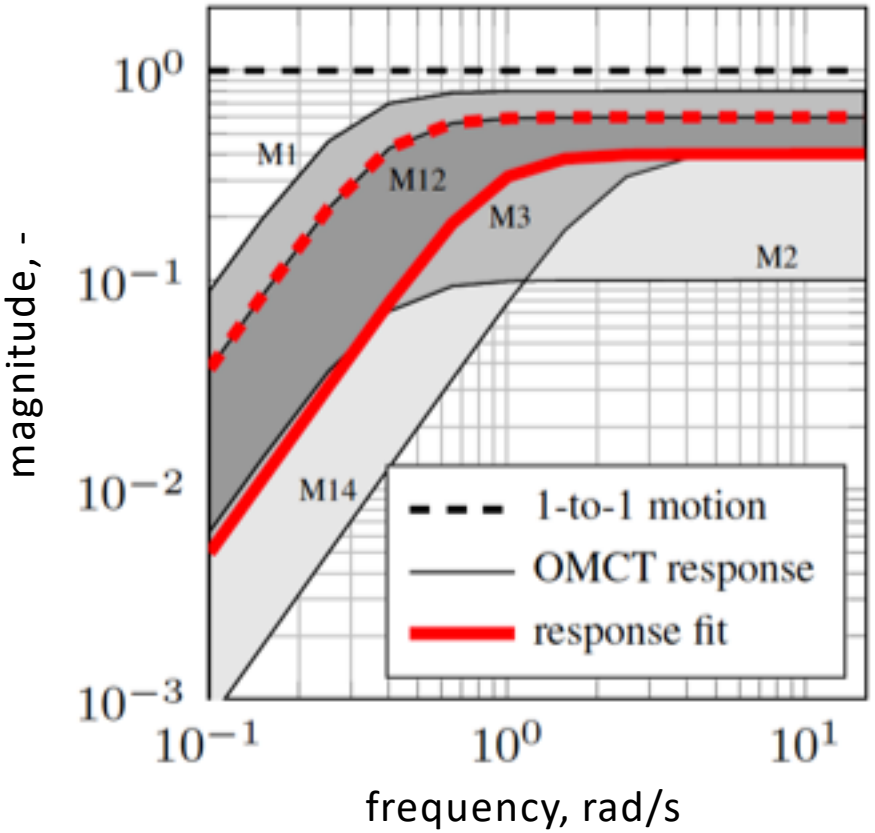


Step 2:
Heave uncertainty bounds

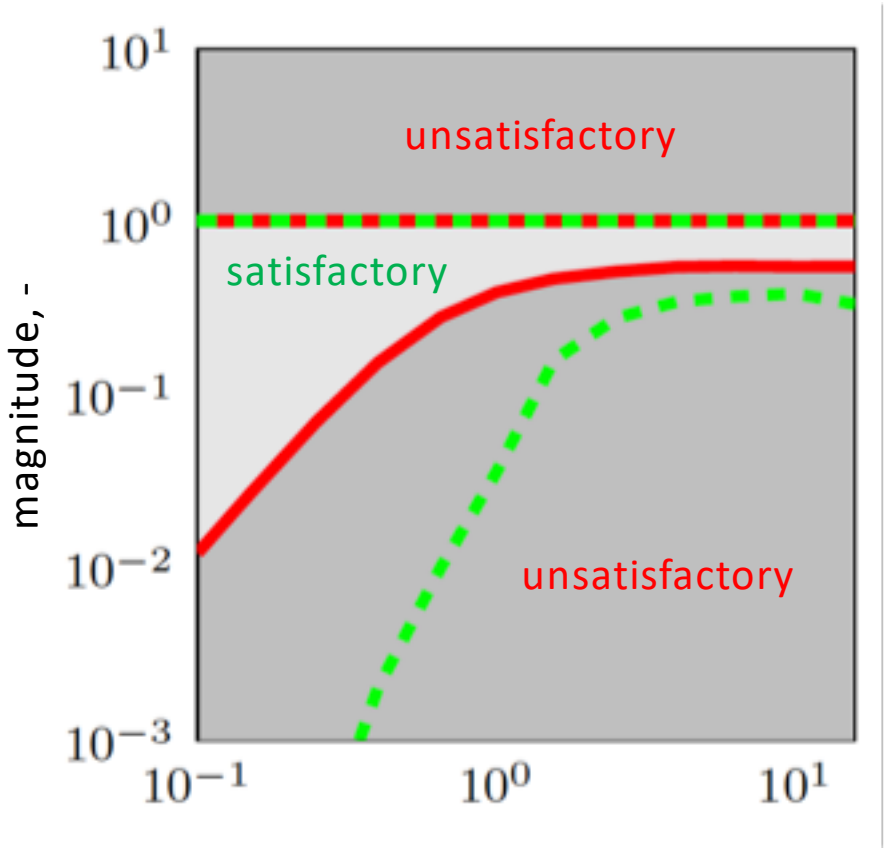


Results
Objective Motion Cueing Criteria

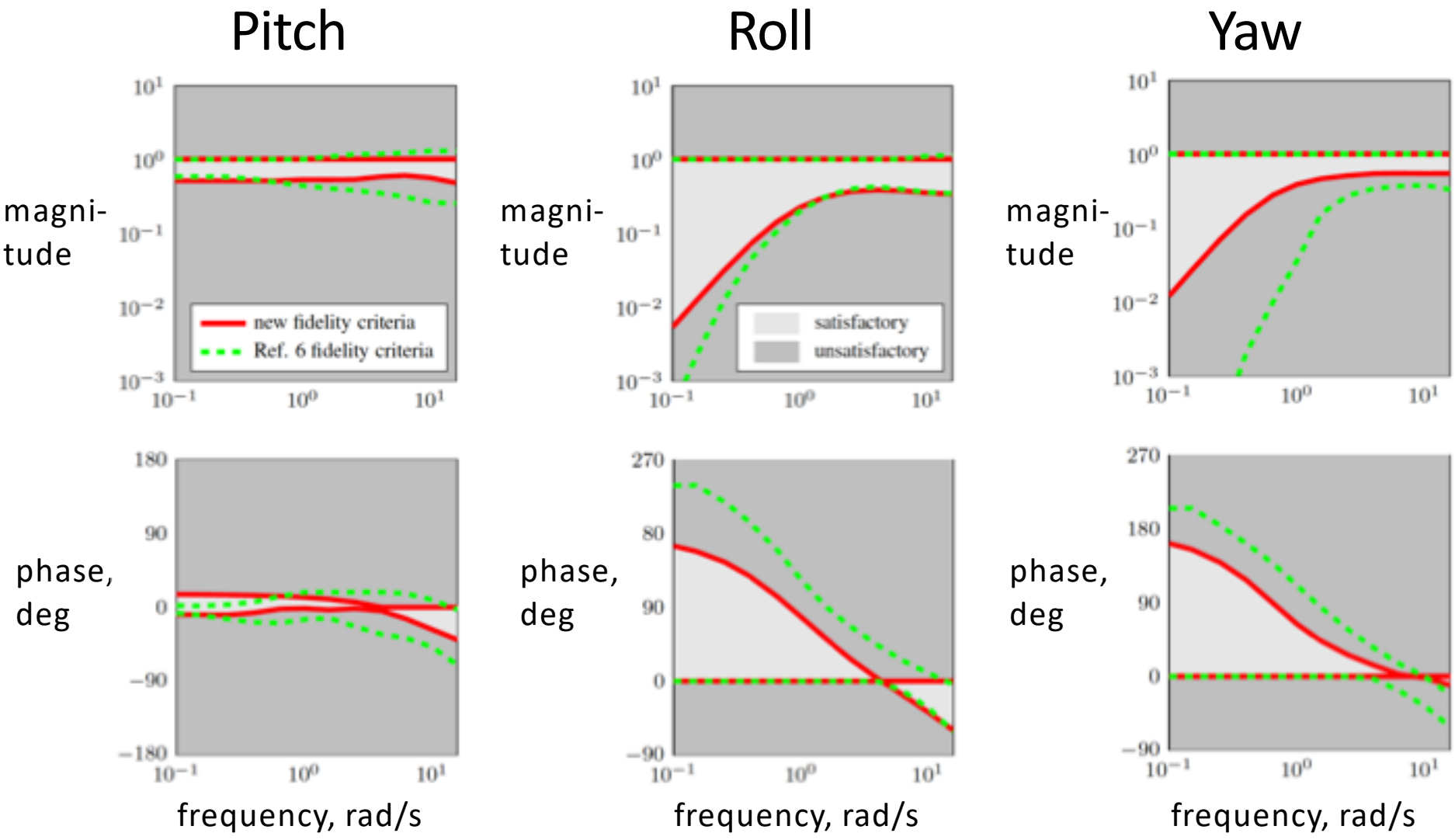
Step 3:
Heave response fit



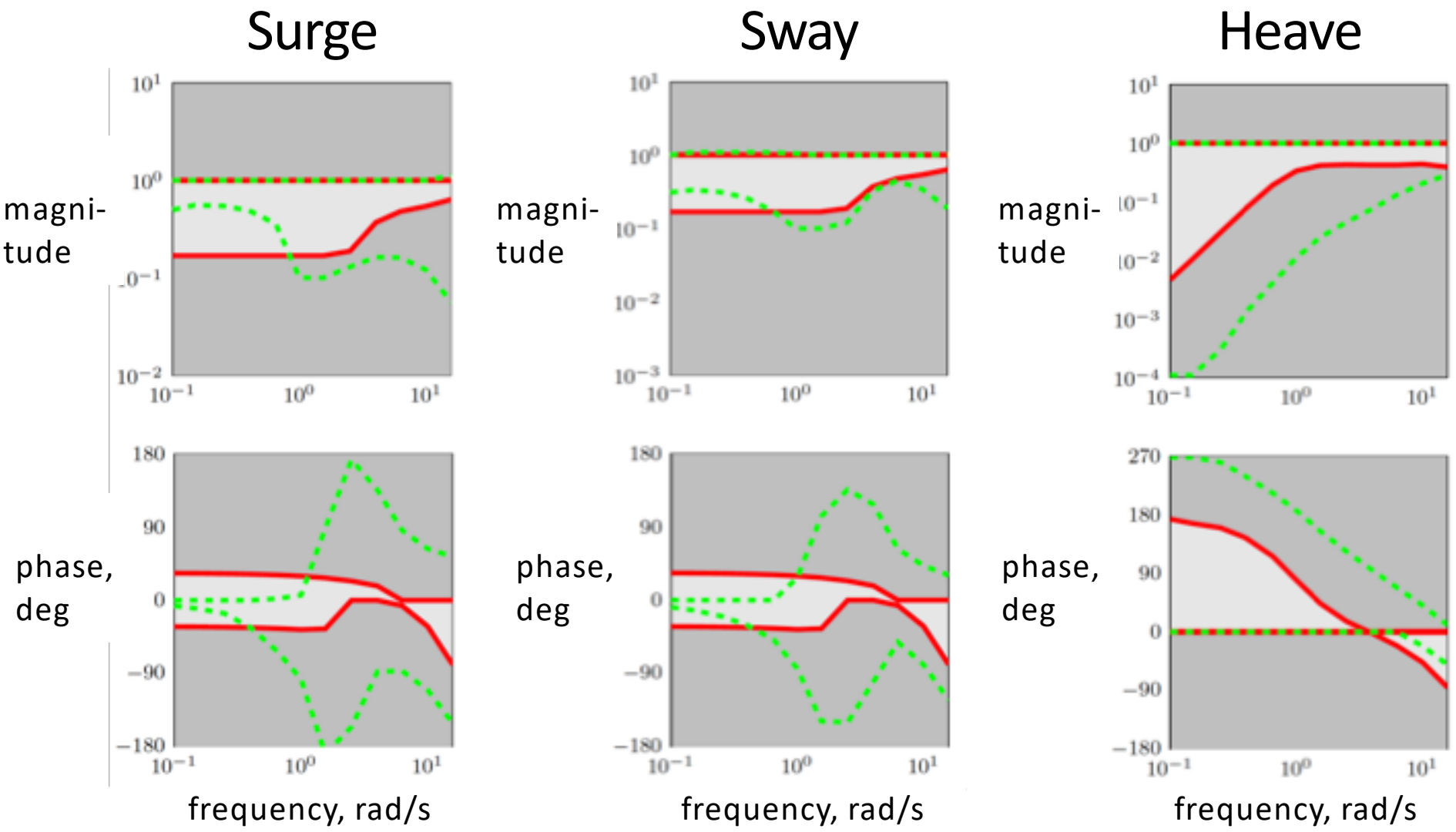
Step 4:
Heave fidelity region



Rotational Motion Cueing Bounds

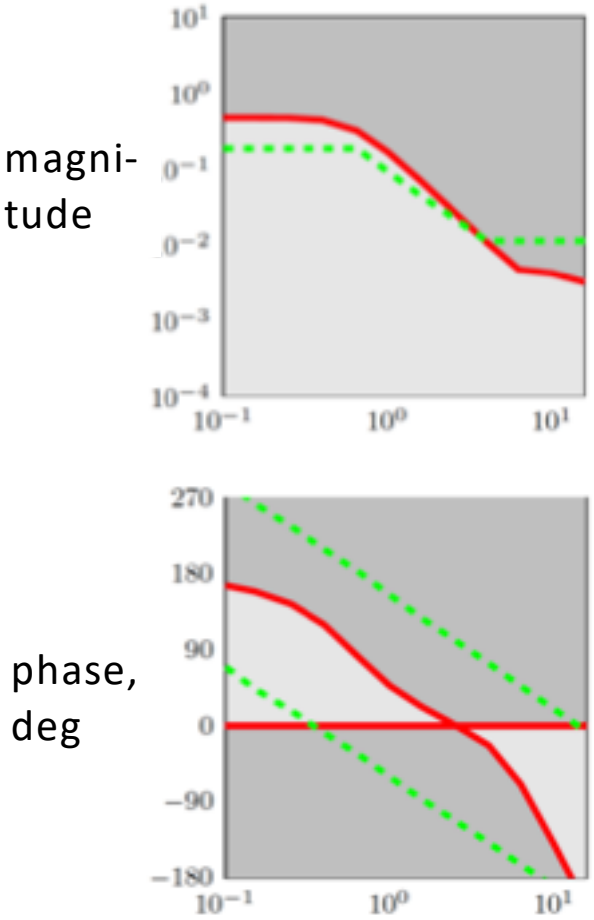


Translational Motion Cueing Bounds

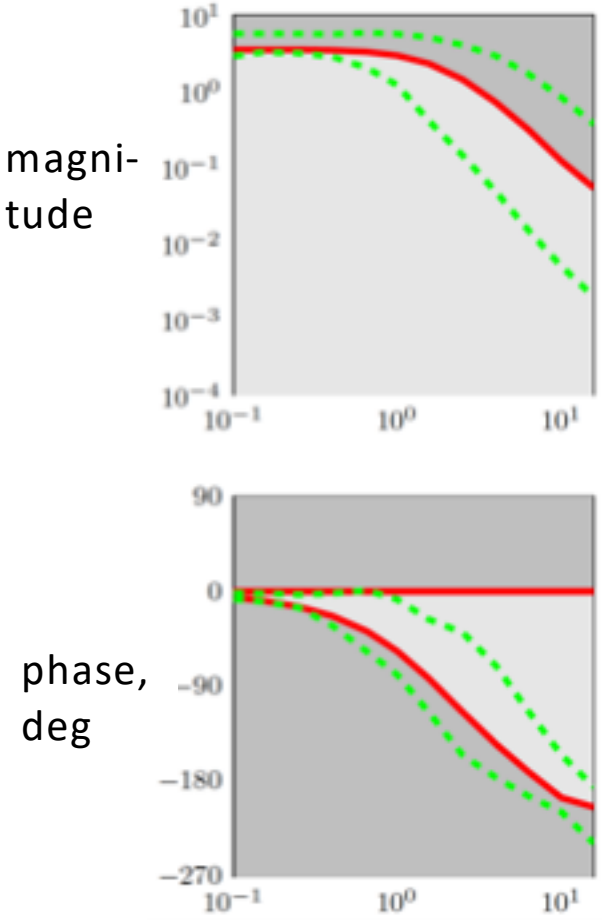


Cross-Coupling Bounds

Roll to sway



Surge to pitch



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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