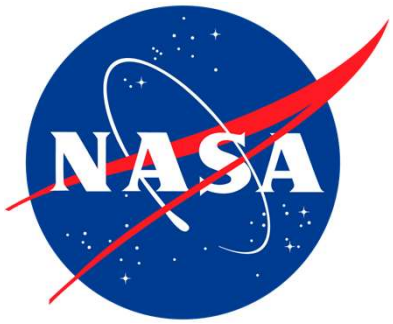
Effects of Motion Fidelity on Pilot Performance using Mixed-Reality Visuals

Peter Zaal, Ph.D. (Metis Technology Solutions, Inc.), Matt Blanken (NASA), Samuel Orth (Symvionics, Inc.), and Supreethi Penmetcha (NASA)

NASA Ames Research Center

Paul Slade

Quantum3D, Inc.



QUANTUM3D

TRAINING. SIMULATION. TECHNOLOGY.

Introduction

1. Head-mounted-displays (HMDs) have the potential to revolutionize pilot training in simulators

2. The lack of knowledge of the effects of HMDs on pilot performance in skill-based tasks limits their use for training:
   - Limited regulatory standards exist for using HMD technologies in pilot training
   - No certification standards exist for simulators using HMDs

3. One of the main unknowns is how simulator motion affects pilot performance and training with HMDs
   - Some argue that motion systems are not required

Introduction

Objective:

Determine the effects of simulator motion fidelity on pilot performance using mixed-reality visuals in a vertiport approach task

What's new?

1. Four motion configurations with mixed-reality
2. Motion effects with Lift-Plus-Cruise eVTOL and Simplified Vehicle Controls
3. Mixed-reality in the largest vertical motion simulator
4. Sufficiently large pilot pool

Vertical Motion Simulator

- World's largest vertical motion simulator
  - 60-ft vertical and 40-ft lateral travel
- Interchangeable cockpits

340+ simulation studies conducted, primarily for research in:

- Handling Qualities of Aircraft and Spacecraft
- Flight Controls and Displays
- Simulation Fidelity
- Ride Qualities

Vertical Motion Simulator Facility at NASA Ames Research Center

Cockpit Layout

Mixed-Reality Headset

Virtual Out-the-Window View

Head Tracker

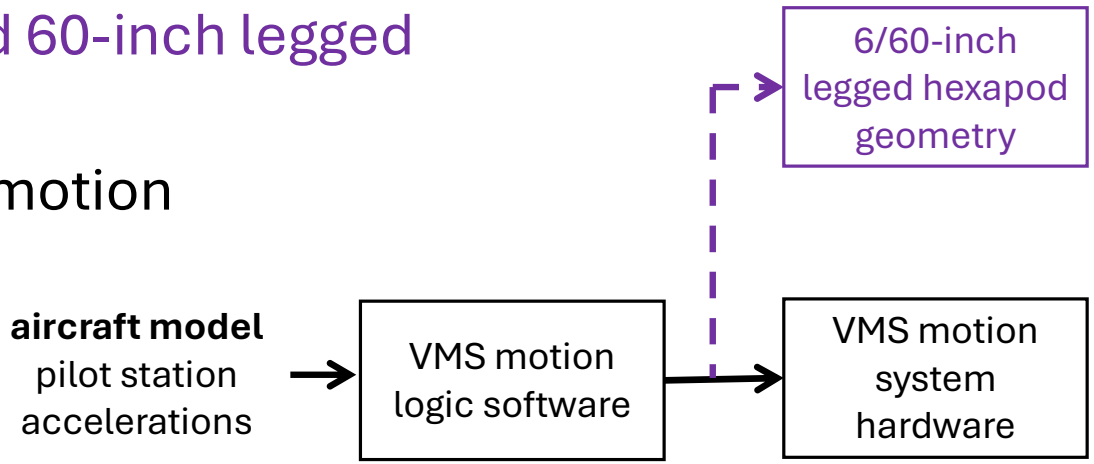
Head Down Displays

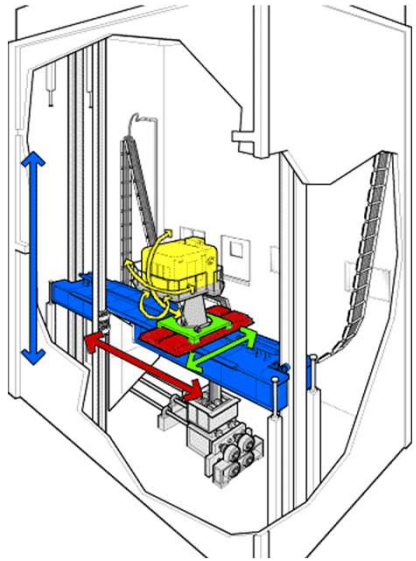
Speed Command Inceptor

Vertical/Lateral/ Directional Command Inceptor (with Twist)

Motion Conditions

1. No motion
2. Simulated 6-inch legged hexapod
3. Simulated 60-inch legged hexapod
4. Full VMS motion





Vertiport Approach Task with Light Turbulence taken from FAA Test Guide

Experiment Design

- Protocol approved by NASA Institutional Review Board
- 13 pilots recruited; 11 completed the study; 2 dropped out during familiarization due to cybersickness

- After familiarization and training, each pilot flew the task with 4 motion conditions x 3 repetitions

- Pilots received task performance feedback after each run
- Pilots completed two questionnaires after each run

Measures

Two subjective measures:

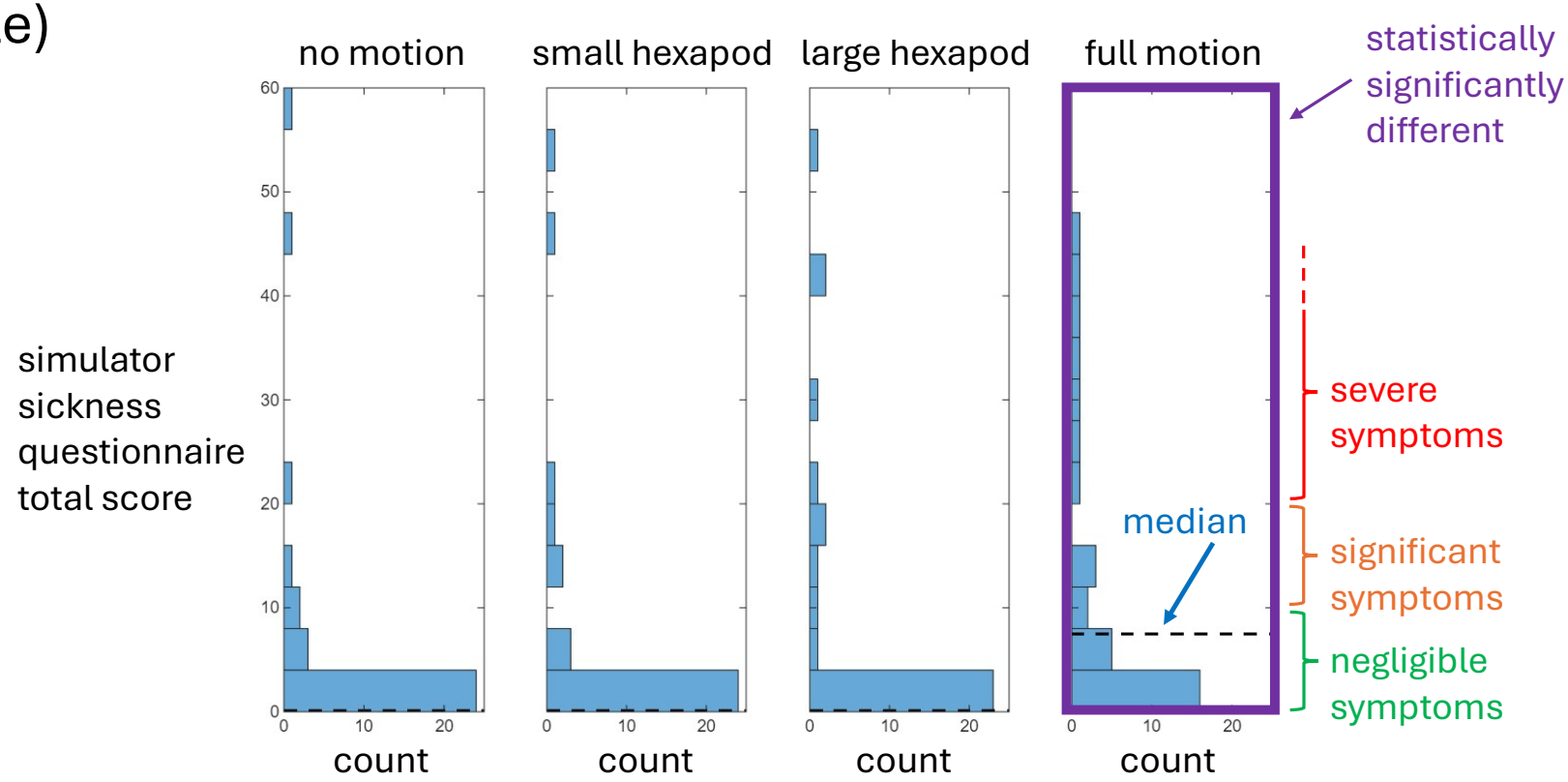
1. Motion rating
2. Simulator Sickness Questionnaire total score

Seven objective task-performance measures:

	Desired	Adequate
3. Maintain glideslope deviation within:	±0.7 deg/±1 dot	±2.1 deg/±3 dots
4. Maintain localizer deviation within:	±0.7 deg/±1 dot	±2.1 deg/±3 dots
5. Height at landing pad boundary crossing from 10 ft within:	±10 ft	±20 ft
6. Groundspeed at landing pad boundary crossing from 5 ft within:	±5 kts	±10 kts
7. Longitudinal deviation from center of landing pad within:	±20 ft	±60 ft
8. Lateral deviation from center of landing pad within:	±20 ft	±60 ft
9. Battery remaining:	≥20:00 min	≥19:40 min

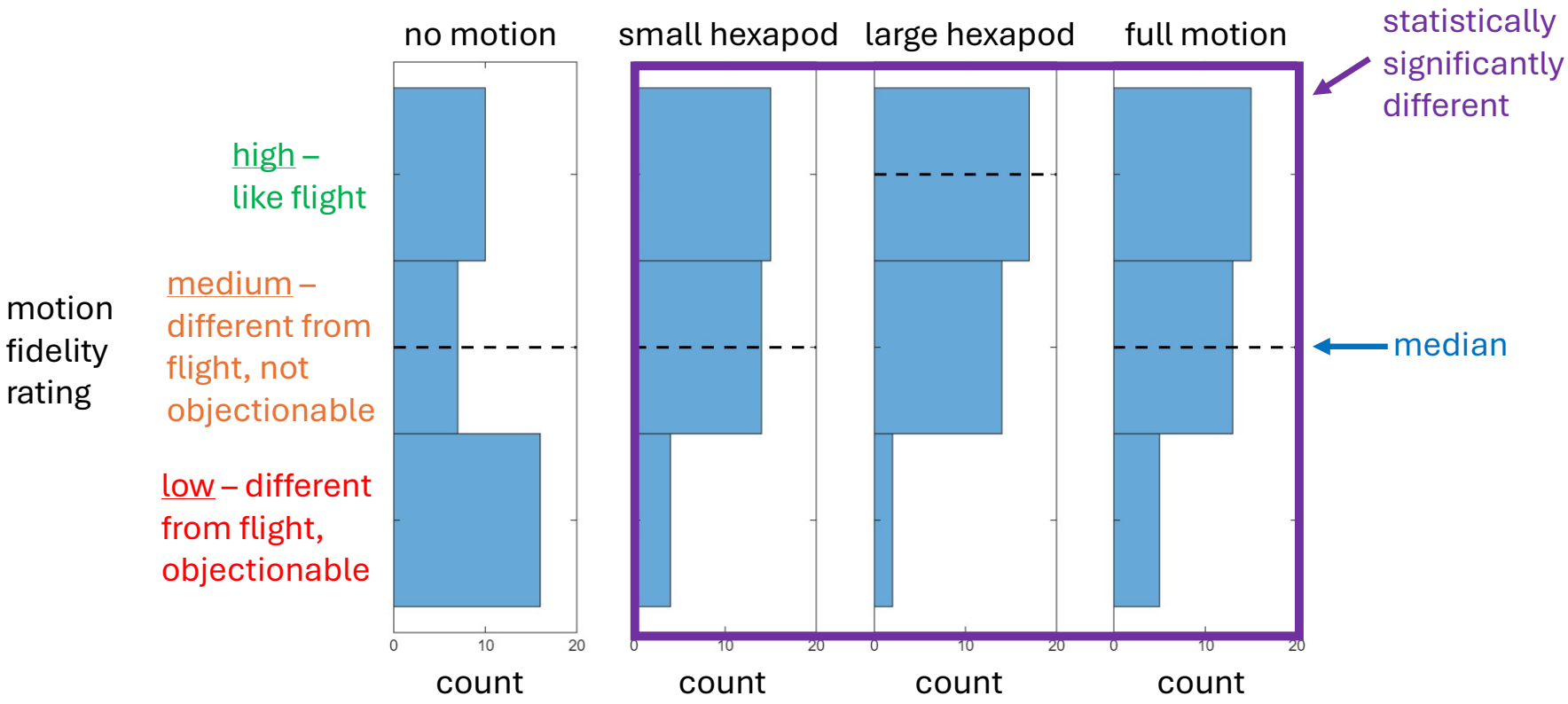
Results – Simulator Sickness

Cybersickness was significantly higher with full motion (but small effect size)



Results – Motion Fidelity Compared to Flight

Motion ratings were significantly higher with motion

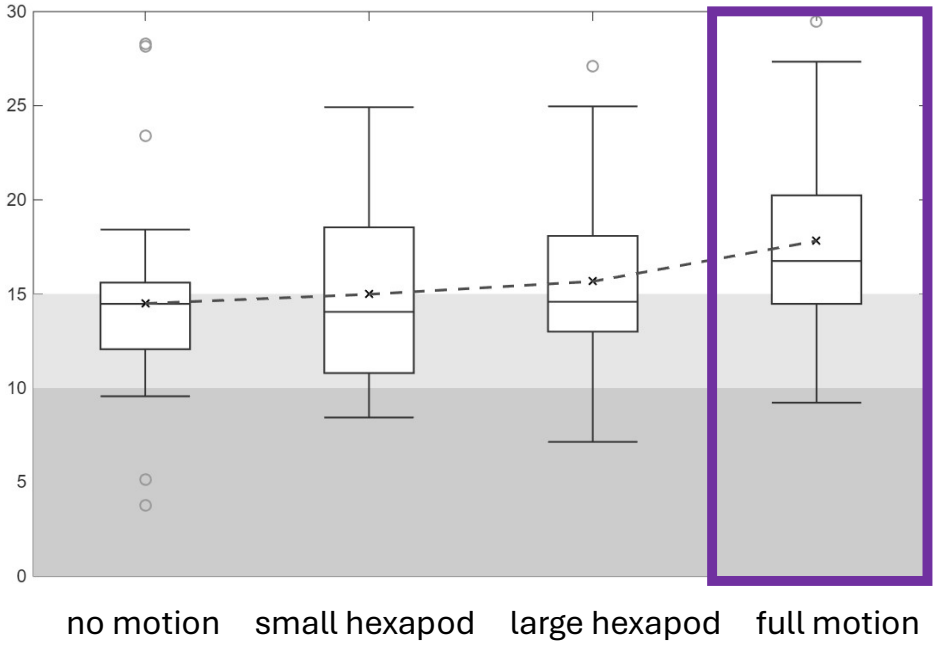


Results – Pilot Performance (1)

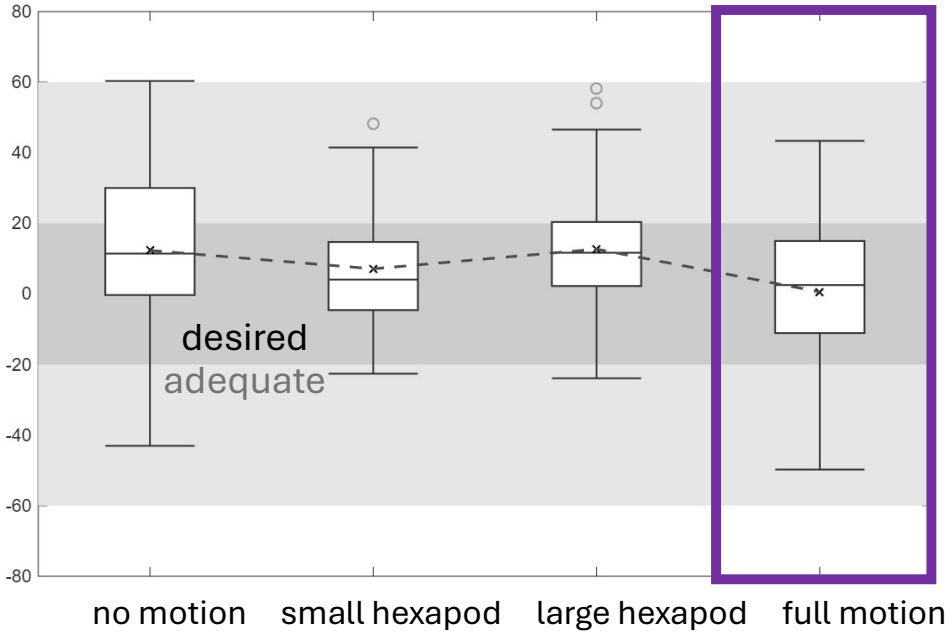
- Landing pad boundary crossings were at significantly higher speeds with full motion
- Landings were significantly closer to the landing pad center under full motion

statistically significantly different

groundspeed at landing pad boundary crossing, kts

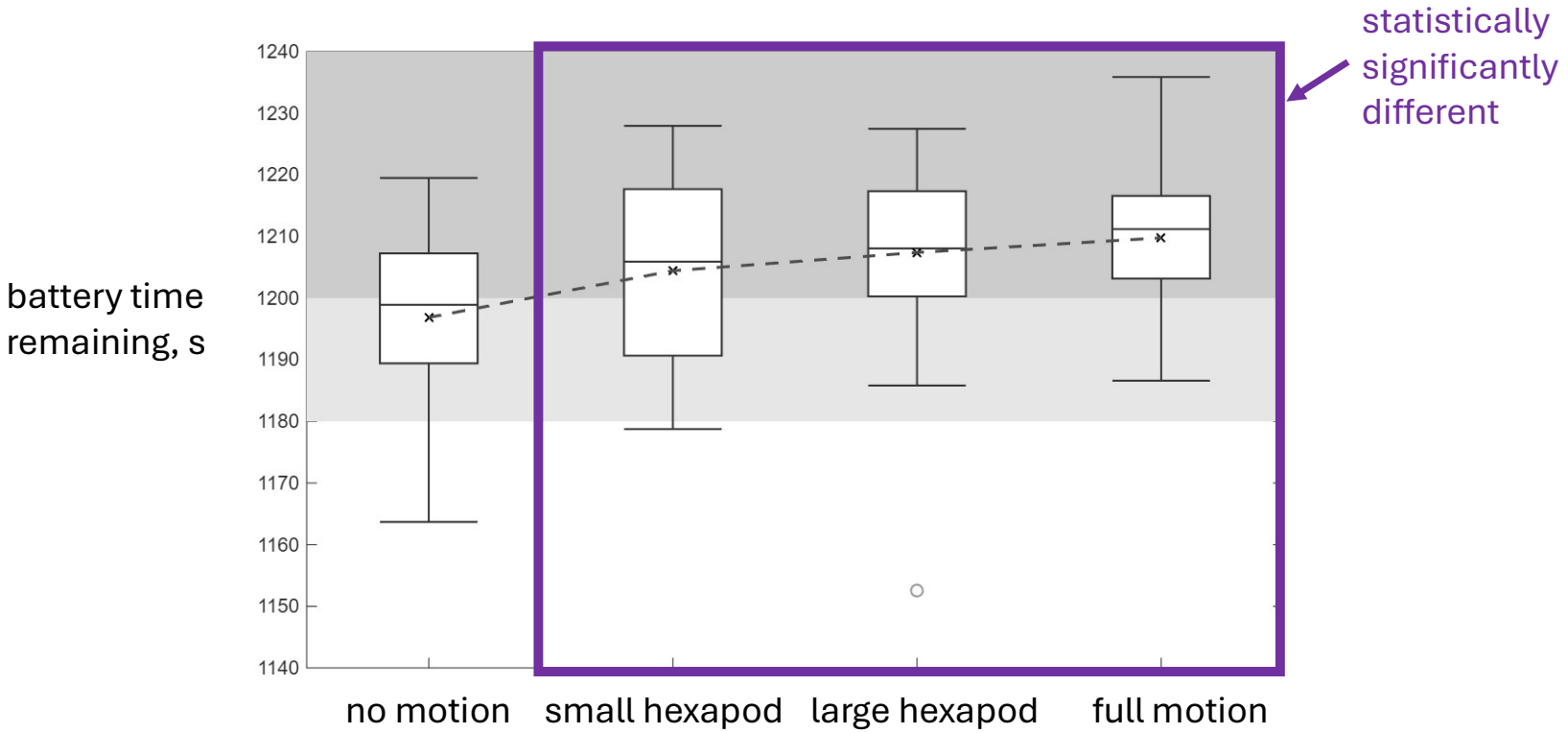


longitudinal touchdown point, ft



Results – Pilot Performance (2)

- Battery time remaining was significantly higher under motion



Conclusions

1. This paper adds initial data to help answer the question: what level of simulator motion is needed in simulators utilizing HMDs?

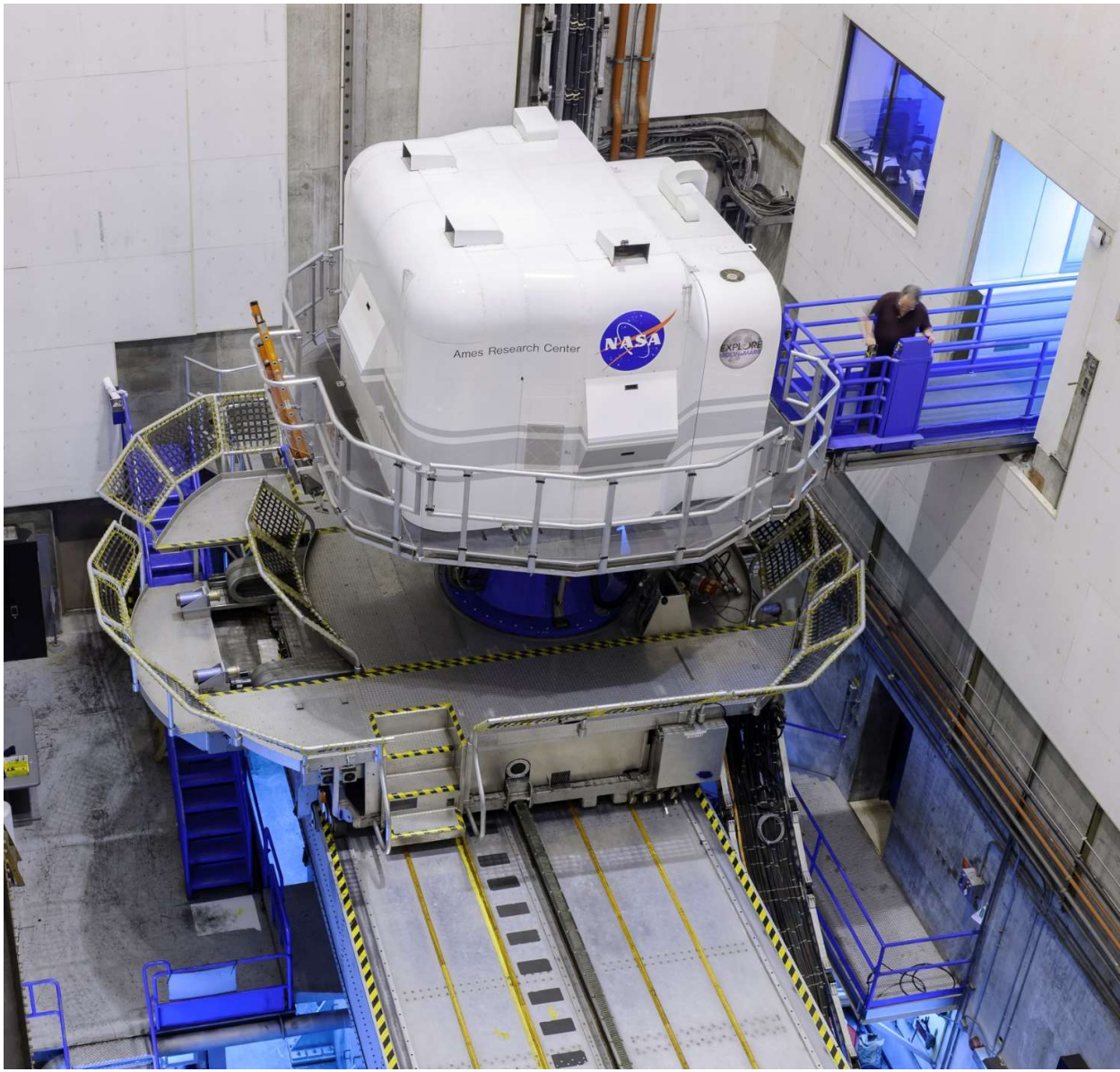
2. Motion condition significantly affected:
   - Cybersickness scores
   - Motion ratings
   - Groundspeed at landing area boundary crossing
   - Longitudinal touchdown point and battery time remaining at touchdown

3. The study results suggest motion systems are required in simulators with HMDs when pilot flying performance needs to be close to that in flight (for example, during initial and recurrent checks)

Questions

Peter Zaal

peter.m.t.zaal@nasa.gov



Backup Slides

Lift-Plus-Cruise eVTOL Aircraft

- Simplified Vehicle Controls (SVC)

Lifting Modes *f*(KIAS)	Left Stick	Right Stick			Groundspeed
	Speed *Accelerate* / *Decelerate*	Vertical *Descend* / *Climb*	Lateral *Go Left* / *Go Right*	Directional *Yaw Left* / *Yaw Right*	
TB Lift (0-20 KIAS)	Acceleration[1]	Vertical Acceleration	Bank Angle	Heading Rate	(0-34 KGS)
STB Lift (15-40 KIAS)		FPA Rate			(34+ KGS)
SWB Lift (30-100 KIAS)	Acceleration[2]		Roll Rate	Sideslip Angle	
WB Lift (90-120 KIAS)					

(1) Acceleration is relative to forward groundspeed
(2) Acceleration is relative to indicated airspeed

Kaneshige et al., "Simplified Vehicle Control Concept for a Lift Plus Cruise eVTOL Vehicle," AIAA AVIATION Forum and ASCEND 2024

Questionnaires

Motion Fidelity Rating

Fidelity rating	Definition
High	Motion sensations are like those of flight
Medium	Motion sensations are noticeably different from flight, but not objectionable
Low	Motion sensations are noticeably different from flight and are objectionable

Simulator Sickness Questionnaire

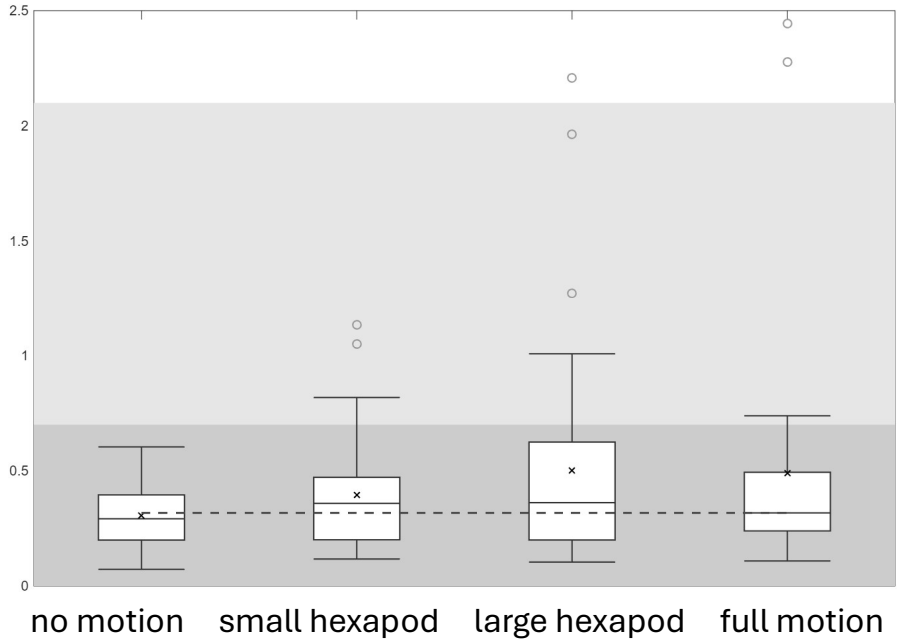
(circle severity of each symptom below)

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficulty focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. Fullness of the Head	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eyes closed	None	Slight	Moderate	Severe
14. Vertigo	None	Slight	Moderate	Severe
15. Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

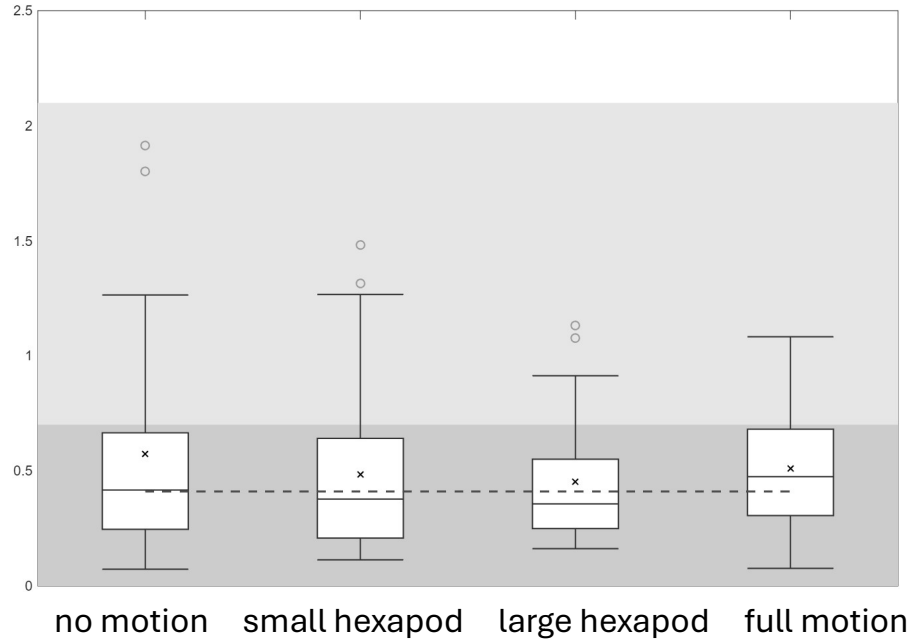
Results

No significant effects on glidepath tracking

RMS glideslope deviation, deg



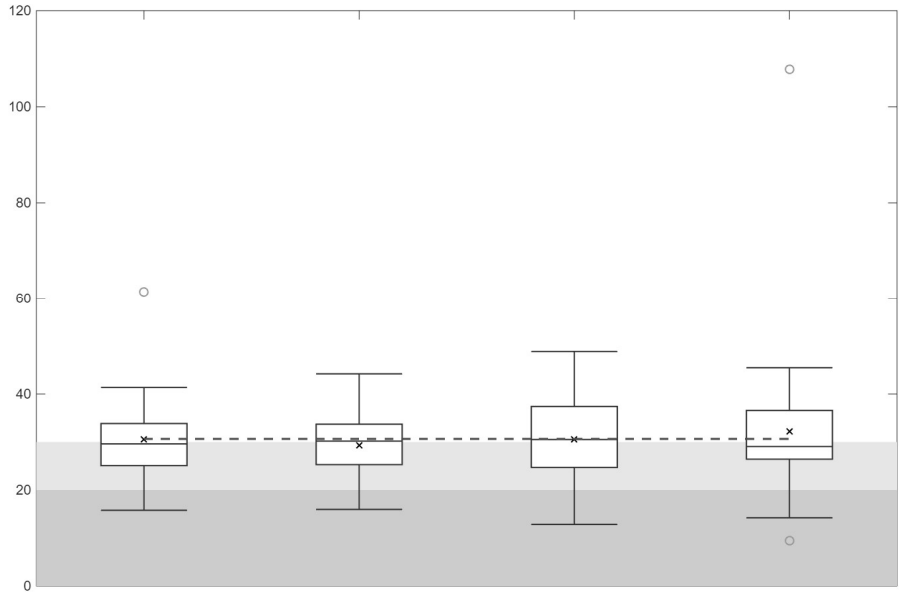
RMS localizer deviation, deg



Results

No significant effects on landing pad boundary crossing height and lateral touchdown position

height at landing pad boundary crossing, ft



lateral touchdown point, ft