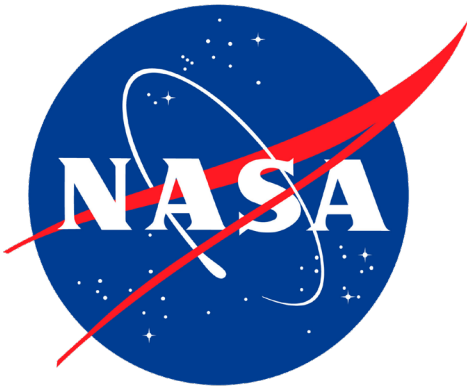


Evaluation of a Mixed-Reality Headset for Handling Qualities Testing

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

NASA Ames Research Center



Vikrant Sharma and Lorenzo Comelli
National Test Pilot School



69th Annual Symposium & Banquet, 24-27 September 2025

Handling Qualities for Military Rotorcraft

During the design, development, production, and acceptance of new military rotorcraft, handling qualities evaluations are carried out in accordance with Detail Specification MIL-DTL-32742 (previously ADS-33)

Mission-Task Elements (MTEs)



Mission-Specific Criteria
(e.g., desired vs. adequate,
utility vs. attack)



Performance Metrics
(evaluated using Cooper-Harper
Rating Scale)

Handling Qualities depend on:

1. Flying characteristics
2. Primary piloting task
3. External factors (e.g., wind/turbulence)
4. Secondary tasks
5. Visual Cueing

Simulation for Handling Qualities Evaluations

- Many design requirements allowed to be verified through simulations up until the First Flight Readiness Review (FFRR)
- Most simulators use large projector-based out-the-window (OTW) visual systems
- Virtual- or mixed-reality headsets can increase immersion at a reduced footprint

Challenge for widespread use:

No standards for handling qualities evaluations or pilot training exist for virtual or mixed-reality headsets



Simulated Day Useable Cue Environment

1. Simulator visual systems affect Handling Qualities Ratings (HQRs) obtained in a simulator
2. Evaluation of a simulator's visual cueing environment must be carried out
3. Concept of MIL-DTL-32742 Useable Cue Environment (UCE) can be applied to simulated visuals: Simulated Day Useable Cue Environment (SIMDUCE)

Purpose:

Use the SIMDUCE paradigm to evaluate the UCE of a mixed-reality headset in the Vertical Motion Simulator to quantify the quality of its simulated day visual cues for handling qualities work

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

Cockpit Layout

Virtual Out-
the-Window
View

Head
Down
Displays

Speed
Command
Inceptor

Head Tracker



Mixed-Reality
Headset

Vertical/Lateral/
Directional
Command Inceptor
(with Twist)

Lift-Plus-Cruise eVTOL Aircraft

- Simplified Vehicle Controls (SVC)



Lifting Modes $f(\text{KIAS})$	Left Stick	Right Stick			Groundspeed
	Speed <i>Accelerate</i> <i>Decelerate</i>	Vertical <i>Descend</i> <i>Climb</i>	Lateral <i>Go Left</i> <i>Go Right</i>	Directional <i>Yaw Left</i> <i>Yaw Right</i>	
Hover Engaged	Forward Groundspeed	Vertical Speed	Lateral Groundspeed	Heading Rate	(0-20 KGS)
TB Lift (0-20 KIAS)	Acceleration ¹	Vertical Acceleration	Bank Angle	Heading Rate	(0-34 KGS)
STB Lift (15-40 KIAS)					
SWB Lift (30-100 KIAS)	Acceleration ²	FPA Rate	Roll Rate	Sideslip Angle	(34+ KGS)
WB Lift (90-120 KIAS)					

(1) Acceleration is relative to forward groundspeed

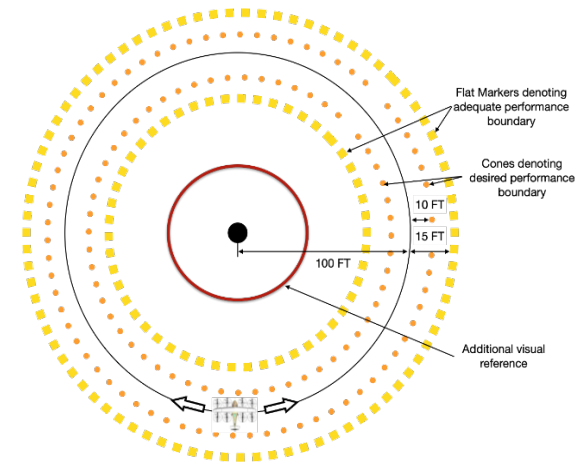
(2) Acceleration is relative to indicated airspeed

1. Hover mode engaged

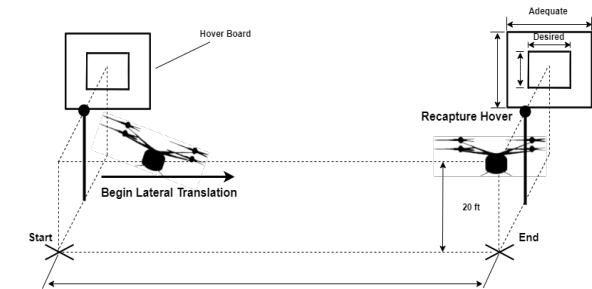
2. Hover mode disengaged

Test Setup and Procedures

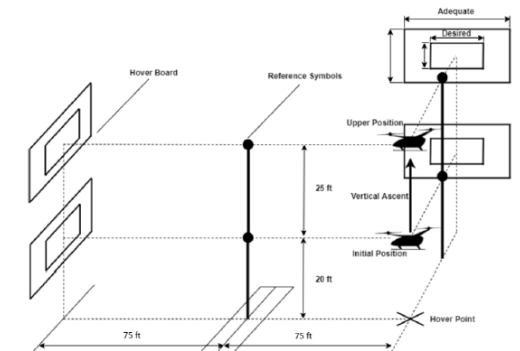
- Nine total pilots: five primarily fixed-wing, four rotorcraft
- Mixed-reality visuals and near one-to-one vehicle motion
- Three Handling Qualities Task Elements (HQTEs) →
- After a familiarization session, at least two training runs per task were used for training, followed by one data collection run
- Aggregate data was used to calculate the Useable Cue Environment and Handling Qualities levels



1. Pirouette



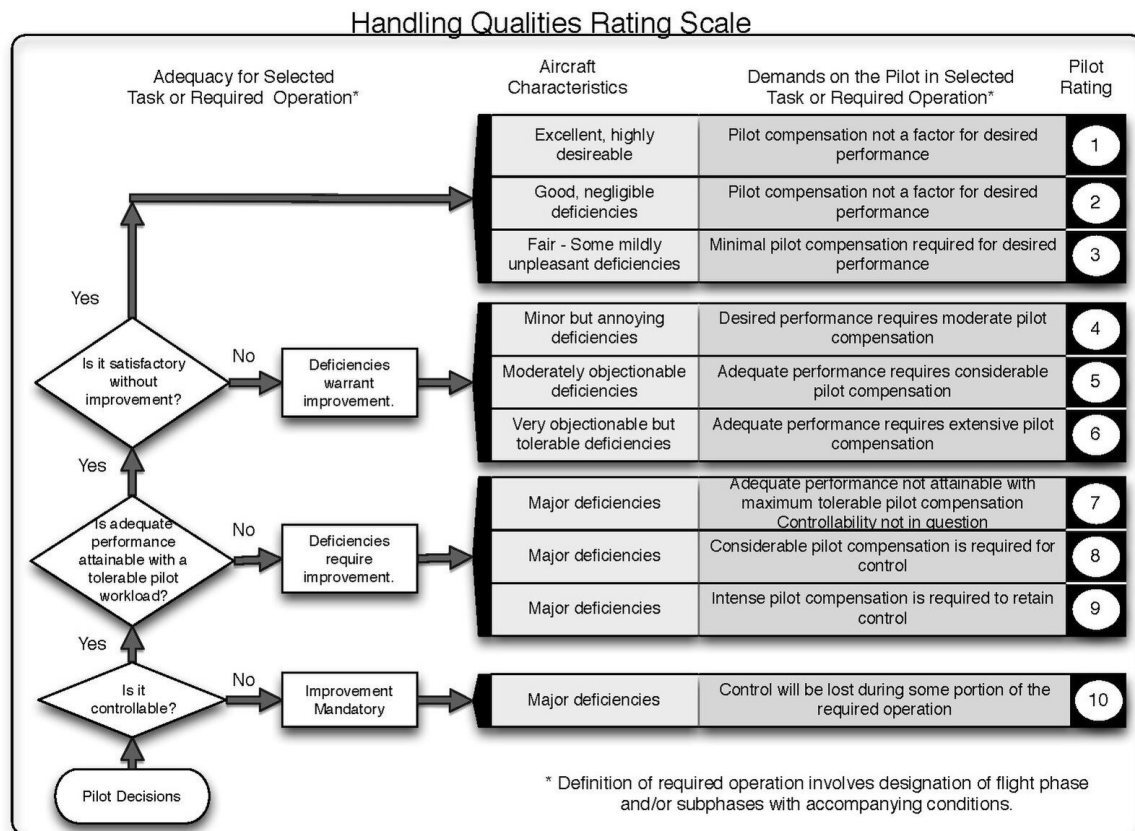
2. Lateral Reposition and Hold



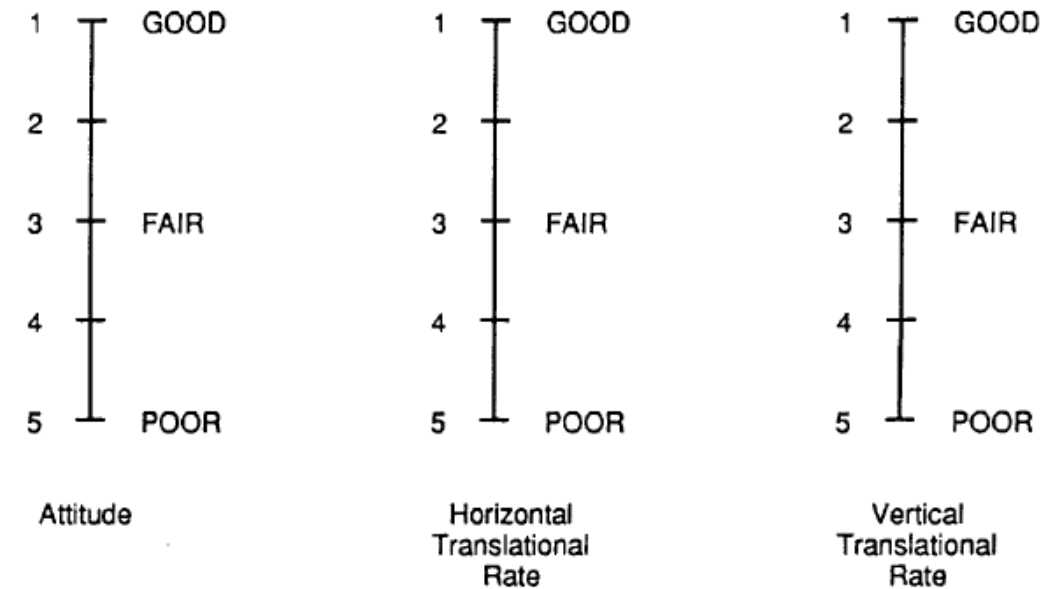
3. Vertical Reposition and Hold

Ratings

1. Cooper-Harper Rating



2. Visual Cue Rating (VCR)



Pitch, roll, and yaw attitudes, and lateral-longitudinal and vertical translational rate shall be evaluated for effectiveness for stabilization and control according to the following definitions:

- GOOD:** Can make aggressive and precise corrections with confidence and precision is good.
- FAIR:** Can make limited corrections with confidence and precision is only fair.
- POOR:** Only small and gentle corrections are possible and consistent precision is not attainable.

Experimental Conditions

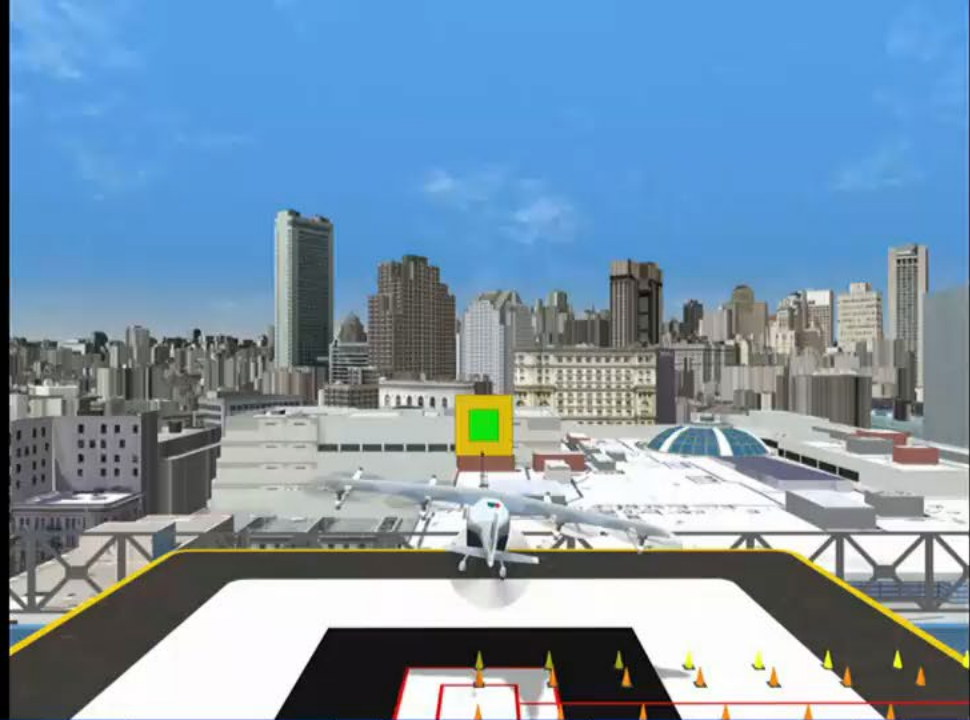
Two separate data collection sessions occurring 6 weeks apart:

Session 1:

- 8 pilots
- Full motion
- Hover mode disengaged
- Mixed-reality visuals only

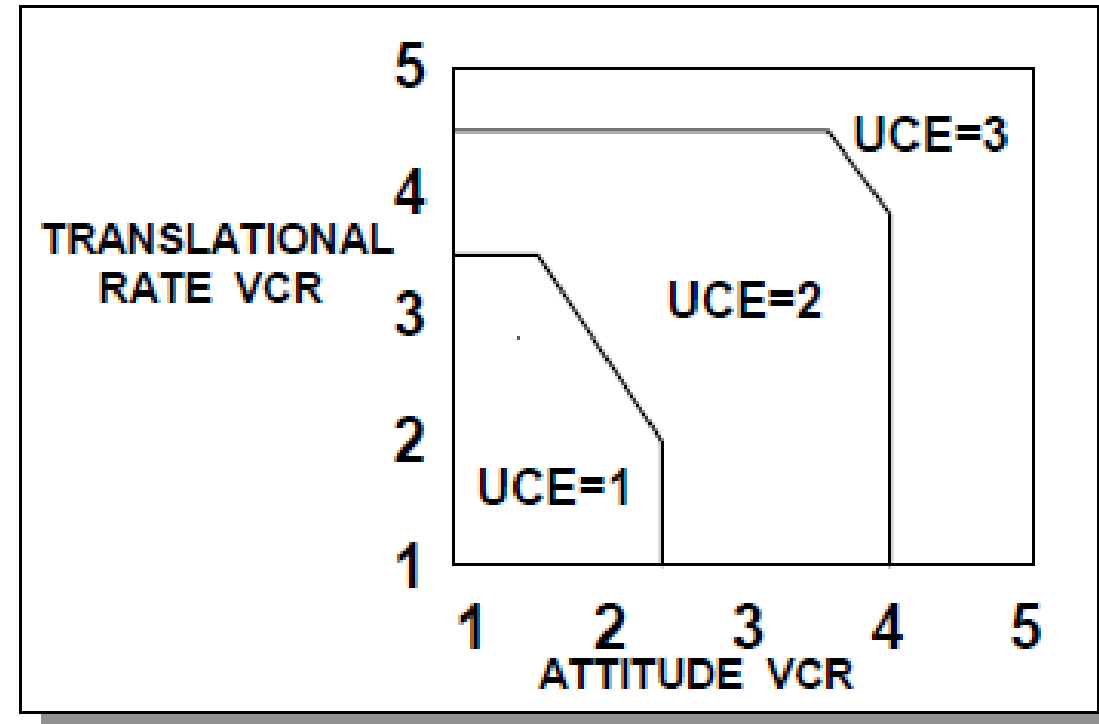
Session 2:

- 3 pilots
- No motion
- Hover mode engaged
- Mixed-reality and conventional visuals (baseline)



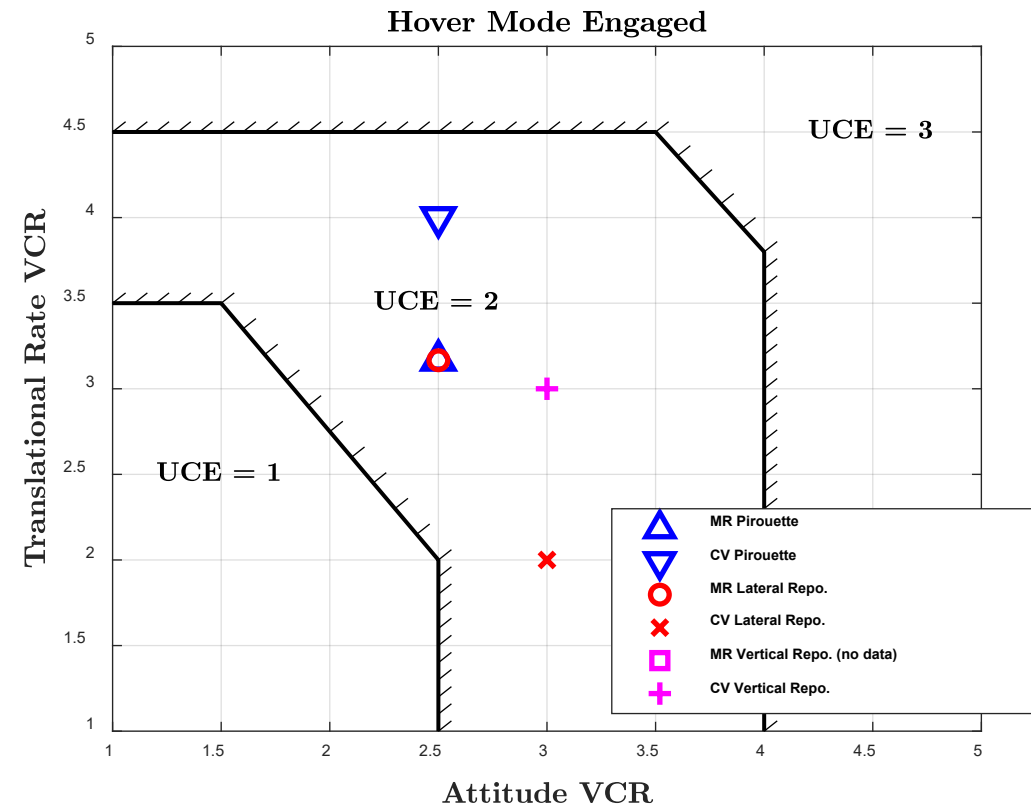
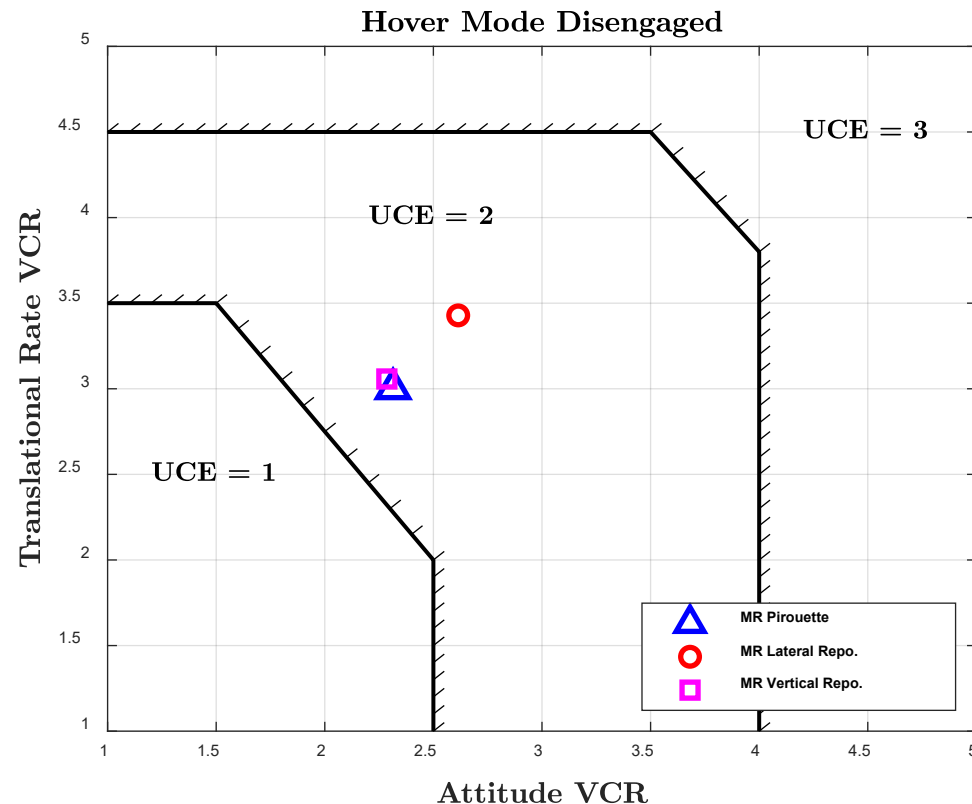
Useable Cue Environment Procedure

- Determine the Visual Cue Ratings (VCRs) for each Handling Qualities Test Element (HQTE) and pilot:
 1. Attitude
 2. Horizontal translational rate
 3. Vertical translational rate
- Plot the averaged worst-case-translational and attitude VCRs on the UCE plot for each HQTE
- The overall UCE is the worst UCE across all tasks
- VCR standard deviations should be less than 0.75 using a minimum of 3 pilots
- UCE and HQ levels should be similar for results to be meaningful



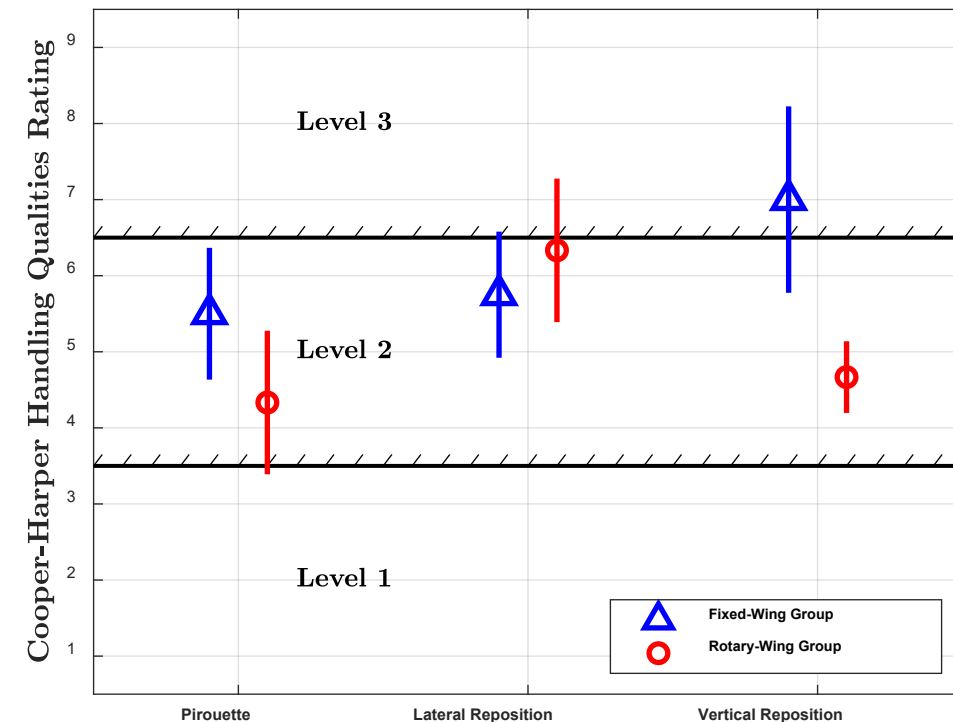
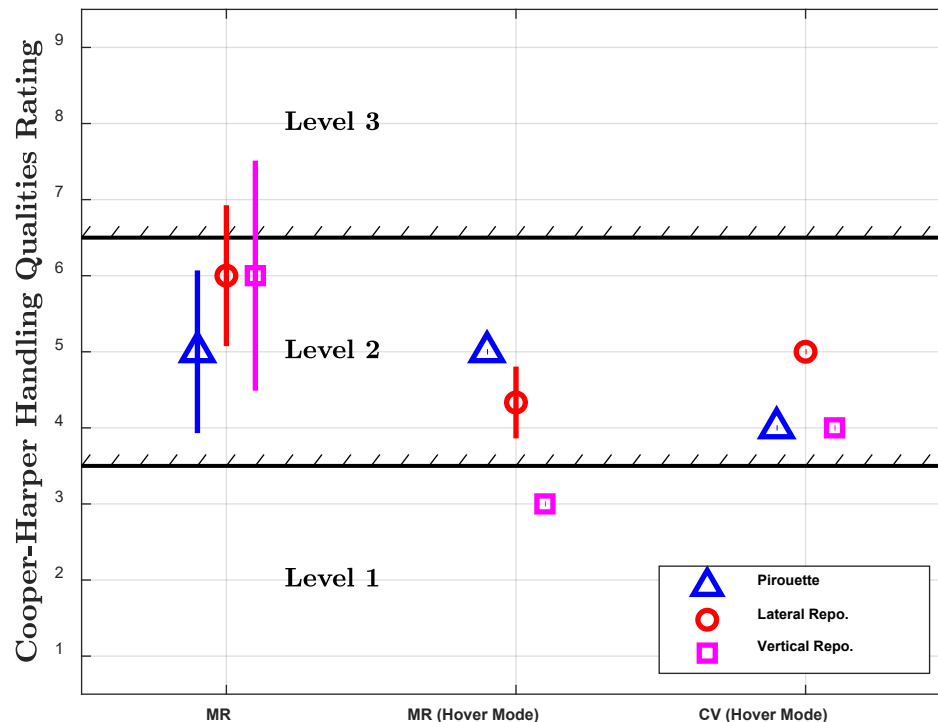
Useable Cue Environment Results

- Useable Cue Environment (UCE) was Level 2 for all conditions
- Standard deviations were generally below 0.75, except for pirouette



Handling Qualities Rating Results

- Handling Qualities were Level 2 and consistent with Useable Cue Environment levels
- Pirouette and vertical reposition and hold rated worse by fixed-wing pilots



Data Limitations

1. Limited sample size in Session 2
2. No direct comparison of mixed-reality and conventional visuals due to difference in image generator hardware and software
3. Real handling qualities levels of eVTOL aircraft are unknown
4. Pilots not familiar with Simplified Vehicle Controls scheme
5. Some Handling Qualities Task Elements (HQTEs) required little attitude control

Mixed-Reality Out-the-Window Visuals



Conventional Out-the-Window Visuals



Lessons Learned

1. The SIMulated Day Useable Cue Environment (SIMDUCE) is a useful starting point in determining the quality of its Useable Cue Environment for handling qualities testing
2. Not all pilot feedback about mixed-reality visuals is reflected in its Useable Cue Environment
3. Pilots should be fully familiar with vehicle controls
4. Make sure pilots are constantly reminded of rating guidelines
5. Handling Qualities Task Elements should be in the same visual database location to reduce variation in visual complexity across tasks

Conclusions

1. The Simulated Day Useable Cue Environment (SIMDUCE) paradigm was successfully applied to determine the Useable Cue Environment (UCE) of a mixed-reality headset, and baseline data for future reference were generated
2. There may be certain properties of virtual- and mixed-reality visuals that warrant further consideration
3. Future work should focus on making a more thorough comparison between mixed-reality and conventional visuals with pilots adequately trained on the vehicle and its control scheme

Questions?

Peter Zaal

peter.m.t.zaal@nasa.gov

Vikrant Sharma

vsharma@ntps.edu

Lorenzo Comelli

icomelli@ntps.edu

