



Proficiency Training and Retention for Manual Crew Override During Simulated Lunar Landing

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Background

Crew control of spacecraft during exploration missions consists of both:

- Planned automated supervisory control
- Unplanned manual override and control

Risk to mission success:

- Microgravity-induced alterations in vestibular sensory processing
- Increased cognitive demand and time pressure
- Limitations in just-in-time training availability

It is important to quantify these effects on operationally relevant tasks as soon as possible following the G-transition to develop appropriate countermeasures.

The present work describes the development of a lunar landing simulation task integrated with a 6DOF motion system, based on planned HLS training.

Manual Piloting Ground Learning Study

Goal: Quantify the **rate of skill acquisition** in first-time users and the **retention of skills**

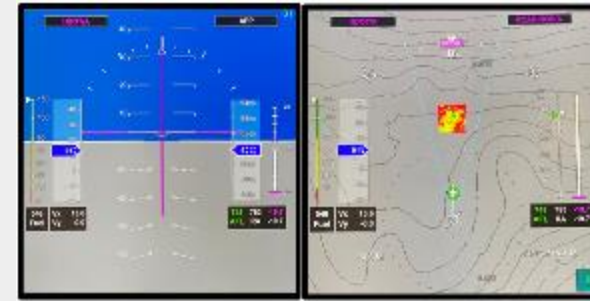
30 healthy non-astronaut participants

- 15 male & 15 female
- 39.07 ± 10.90 years

Piloting Experience	None	19
	Novice	6
	Intermediate	2
	Advanced	1
	Expert	2
Gaming Experience	Never	4
	Rarely	12
	Sometimes	5
	Often	6
	Very Often	3
Handedness	Right	28
	Left	2
Corrective Lenses	Yes	13
	No	17
ROBoT Experience	Yes	4
	No	26
Motion sickness susceptibility	None to minimal	25
	Moderate	5



6DOF Motion Base



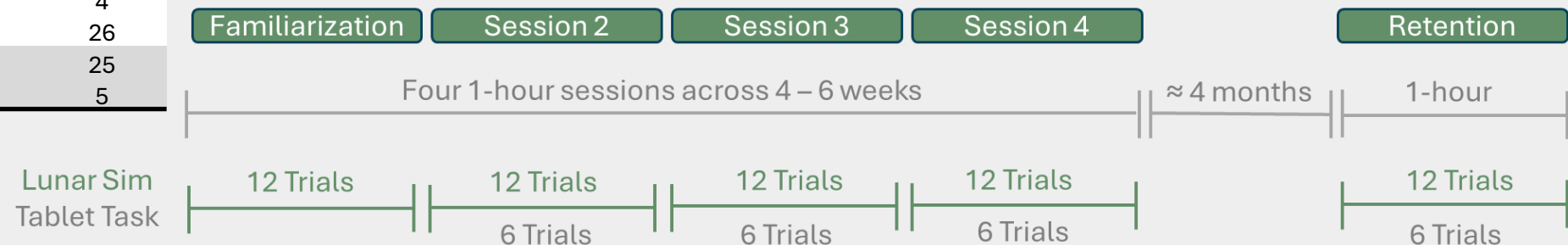
Lunar Landing Sim



Gaze Trackers



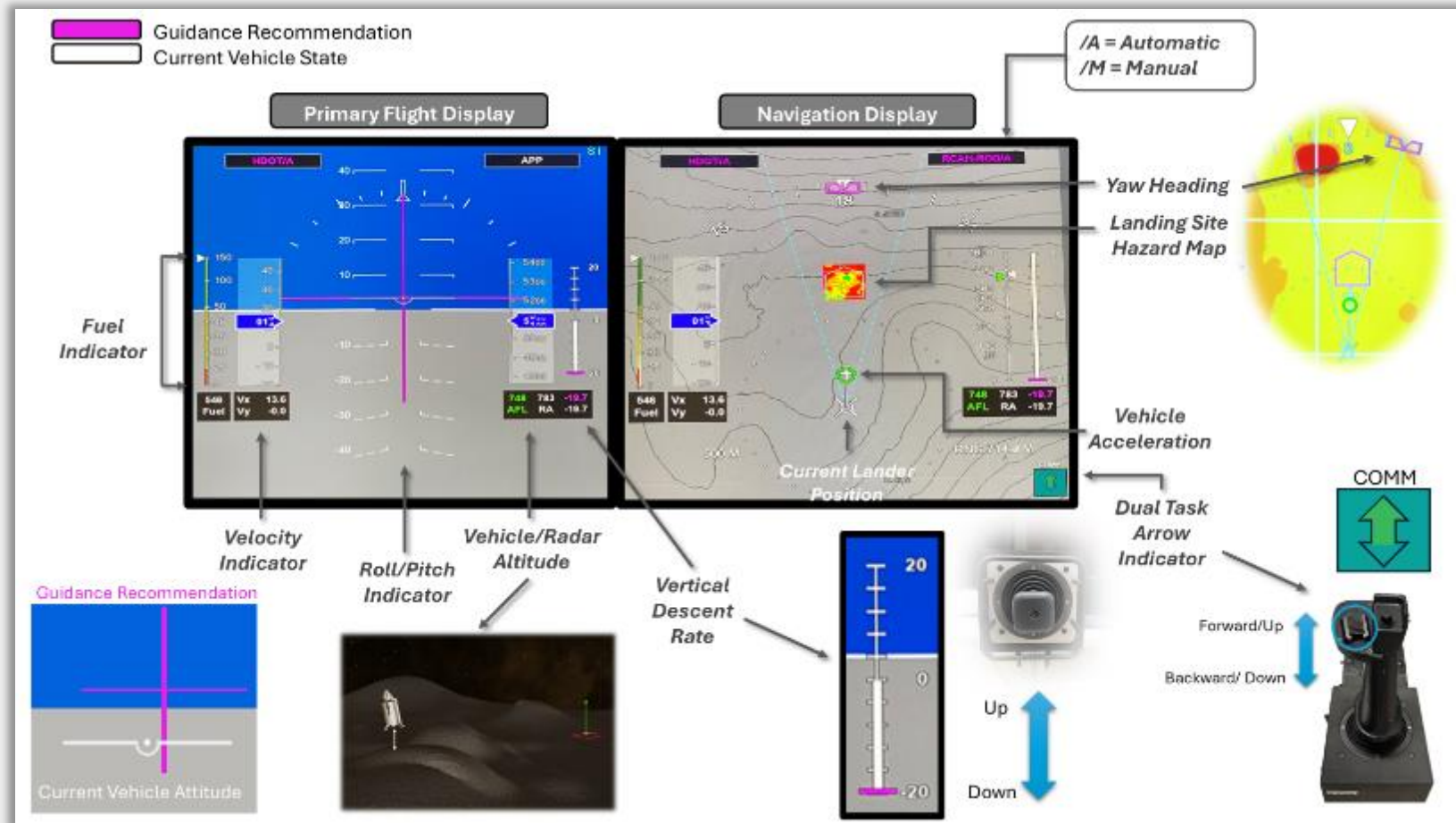
Lunar Tablet Task



Lunar Landing Simulation (LLSim)

Unplanned Manual Crew Override and Control

- Monitor automatic flight trajectory before commanded manual takeover
- Manually control vehicle attitude and rate of descent to nominal or re-designated landing aimpoint
- Simultaneously monitor system displays and warnings requiring pilot input (dual tasking)



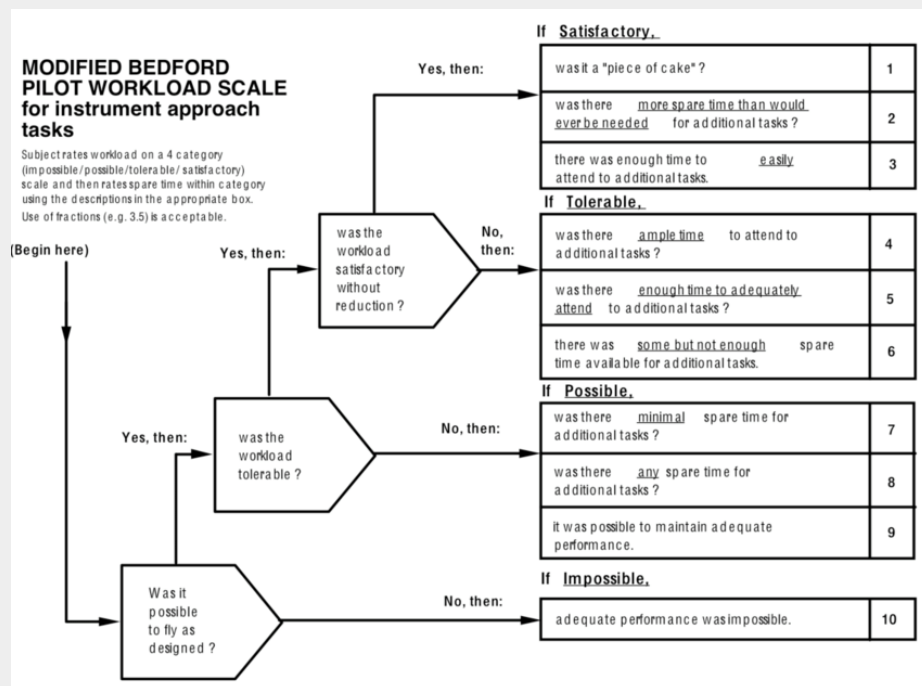
Manual Piloting Performance Metrics

- Touchdown performance = Vehicle state @ touchdown
- Piloting performance = attitude control and sink rate
- Dual-task performance = secondary monitoring task (communications indicator)
- Modified Bedford workload
- Perceived success - NASA Task Load Index (NASA TLX)

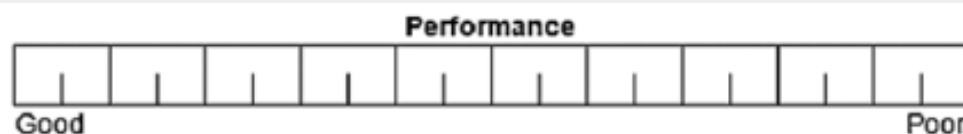
Desired

Adequate

Poor



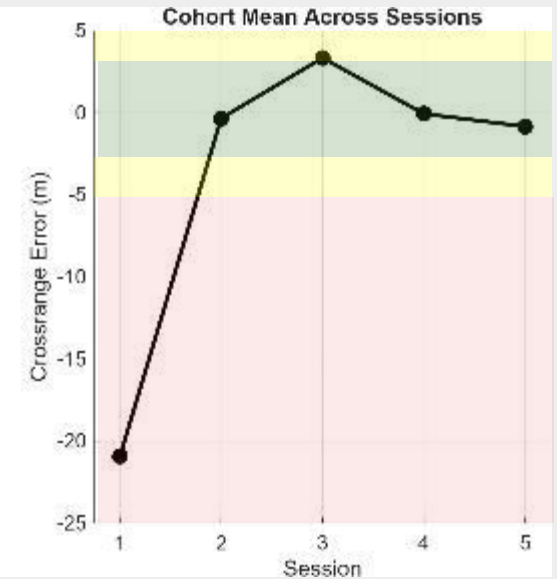
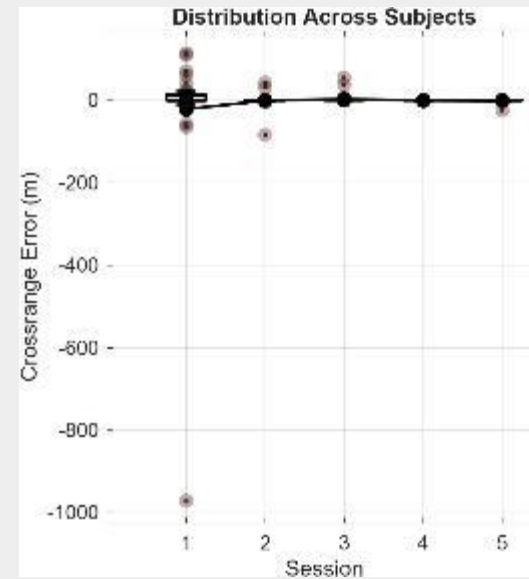
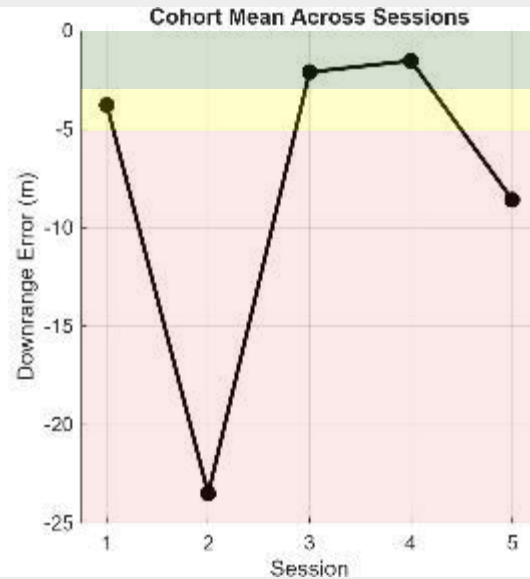
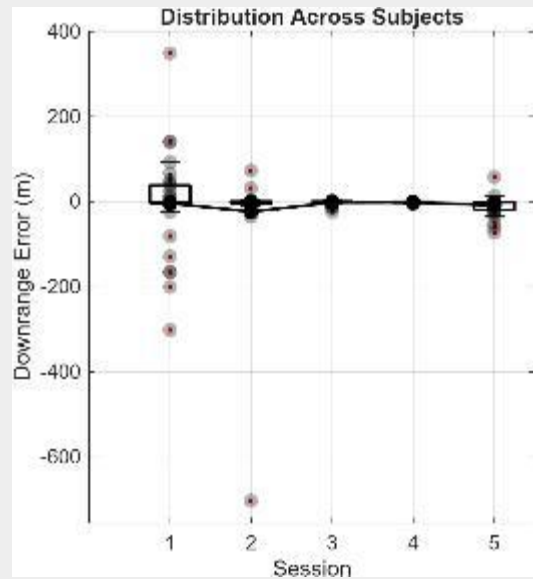
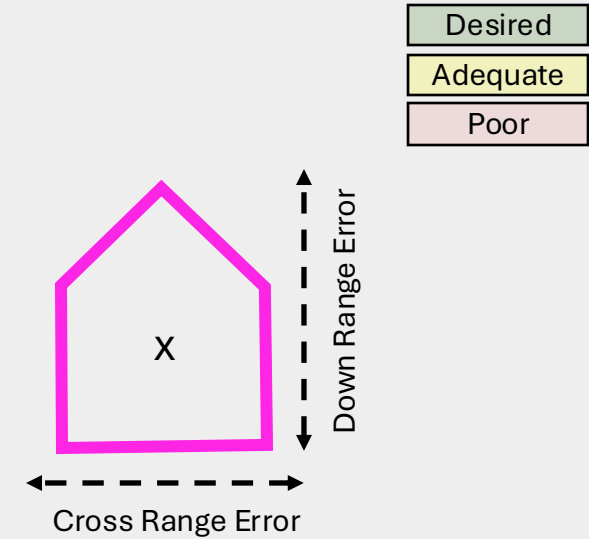
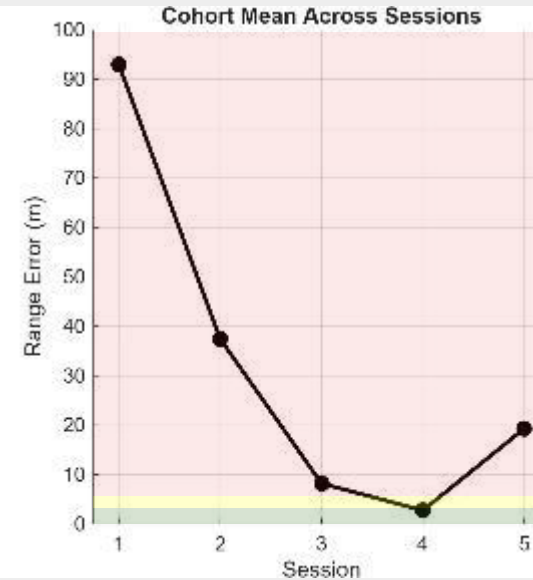
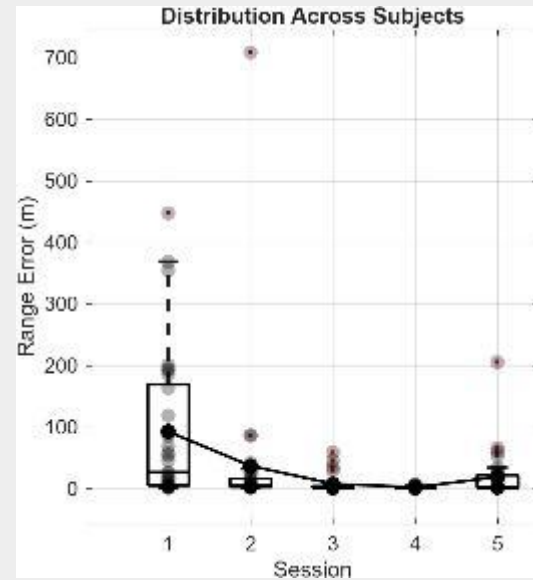
Vehicle State	Desired Criteria Box color = Green Text color = Green	Adequate Criteria Box color = Yellow Text color = Yellow	Poor Criteria Box color = Red Text color = Red
Range to Target at TD [meters]	if $\sqrt{\text{rangeX}^2 + \text{rangeY}^2 + \text{rangeZ}^2} \leq 3$	if $\sqrt{\text{rangeX}^2 + \text{rangeY}^2 + \text{rangeZ}^2} > 3$ && if $\sqrt{\text{rangeX}^2 + \text{rangeY}^2 + \text{rangeZ}^2} \leq 5$	if $\sqrt{\text{rangeX}^2 + \text{rangeY}^2 + \text{rangeZ}^2} > 5$
Descent Rate [m/s]	if $\text{abs}(\text{hDot_mps}) \leq 1.52$	if $\text{abs}(\text{hDot_mps}) > 1.52$ && if $\text{abs}(\text{hDot_mps}) \leq 2.13$	if $\text{abs}(\text{hDot_mps}) > 2.13$
Pitch Angle [degrees]	if $\text{abs}(\text{pitch_deg}) \leq 3$	if $\text{abs}(\text{pitch_deg}) > 3$ && if $\text{abs}(\text{pitch_deg}) \leq 6$	if $\text{abs}(\text{pitch_deg}) > 6$
Roll Angle [degrees]	if $\text{abs}(\text{roll_deg}) \leq 3$	if $\text{abs}(\text{roll_deg}) > 3$ && if $\text{abs}(\text{roll_deg}) \leq 6$	if $\text{abs}(\text{roll_deg}) > 6$
Pitch Rate [deg/sec]	if $\text{abs}(\text{pitchRate_dps}) \leq 3$	if $\text{abs}(\text{pitchRate_dps}) > 3$ && if $\text{abs}(\text{pitchRate_dps}) \leq 6$	if $\text{abs}(\text{pitchRate_dps}) > 6$
Roll Rate [deg/sec]	if $\text{abs}(\text{rollRate_dps}) \leq 3$	if $\text{abs}(\text{rollRate_dps}) > 3$ && if $\text{abs}(\text{rollRate_dps}) \leq 6$	if $\text{abs}(\text{rollRate_dps}) > 6$
Yaw Rate [deg/sec]	if $\text{abs}(\text{yawRate_dps}) \leq 1$	if $\text{abs}(\text{yawRate_dps}) > 1$ && if $\text{abs}(\text{yawRate_dps}) \leq 1.5$	if $\text{abs}(\text{yawRate_dps}) > 1.5$
Heading Error [deg]	if $\text{abs}(\text{yawError_deg}) \leq 5$	if $\text{abs}(\text{yawError_deg}) > 5$ && if $\text{abs}(\text{yawError_deg}) \leq 10$	if $\text{abs}(\text{yawError_deg}) > 10$
Horizontal Speed [m/s]	if $\sqrt{\text{pilot_xVel}^2 + \text{pilot_yVel}^2} \leq 0.61$	if $\sqrt{\text{pilot_xVel}^2 + \text{pilot_yVel}^2} > 0.61$ && if $\sqrt{\text{pilot_xVel}^2 + \text{pilot_yVel}^2} \leq 1.22$	if $\sqrt{\text{pilot_xVel}^2 + \text{pilot_yVel}^2} > 1.22$
Descent Engine Propellant Remaining [kg]	if $\text{deProp_kg} \geq 50$ kg	if $\text{deProp_kg} < 50$ kg && if $\text{deProp_kg} \geq 25$ kg	if $\text{deProp_kg} < 25$ kg
Manual Flight Time [mm:ss]	Time from when the pilot transitions to Manual [out of Auto] until Touchdown on the simulated lunar surface		



How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

Touchdown Performance – Range Error from Target Landing Site

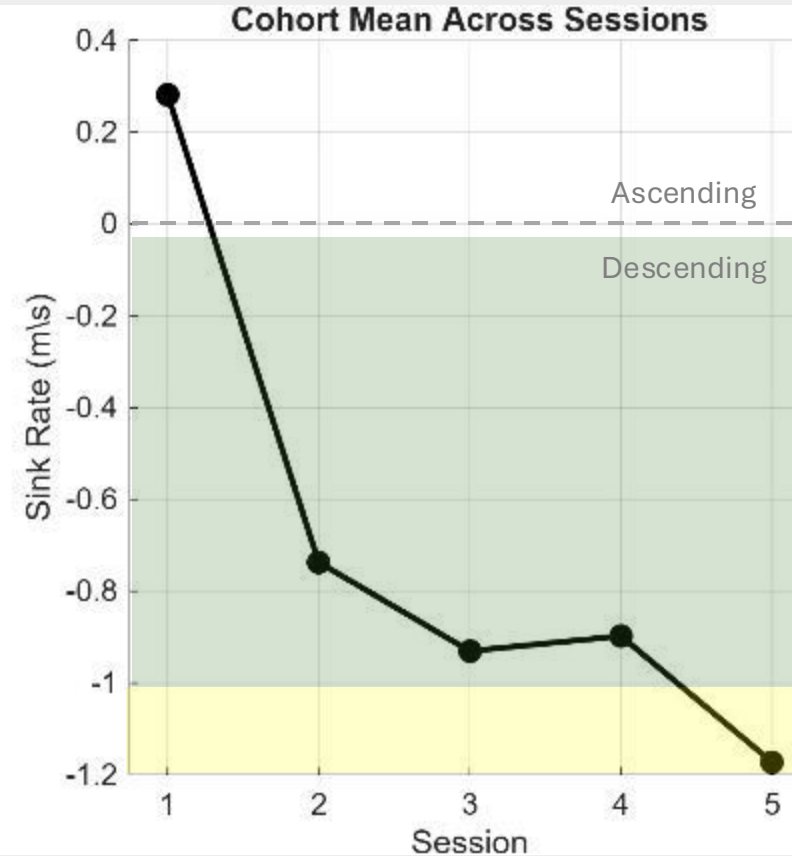
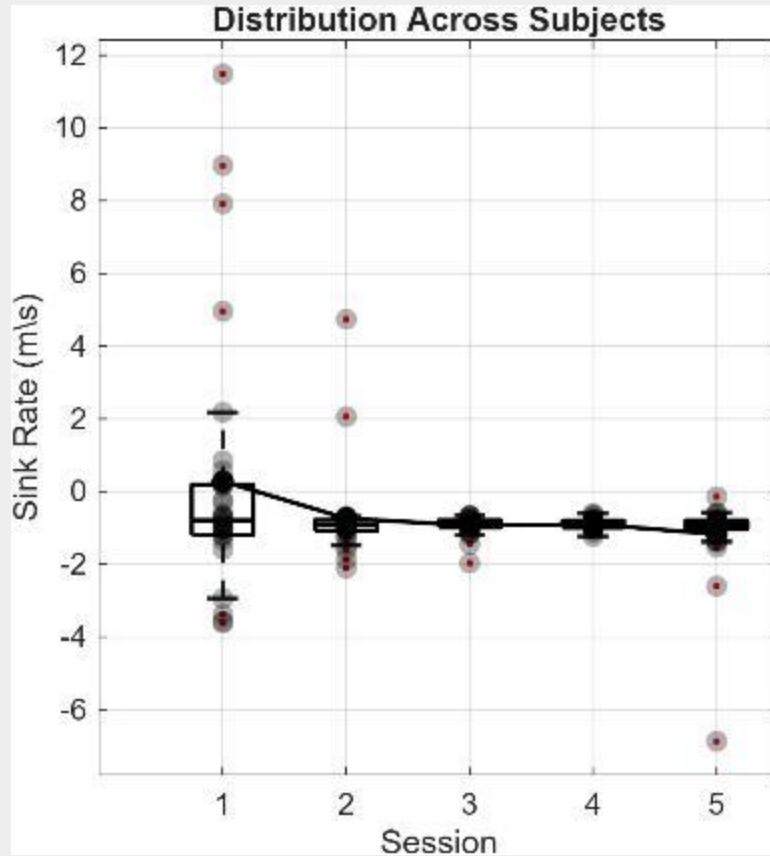
- Considerable learning progression from sessions 1-4
- Reduction in performance after 4-months of non-use
- **Range error** was largely driven by **downrange error**, which could indicate issues with **hdot/sink rate** or attitude control particular in **pitch axis**



Touchdown Performance – Descent Rate at Touchdown

Desired
Adequate
Poor

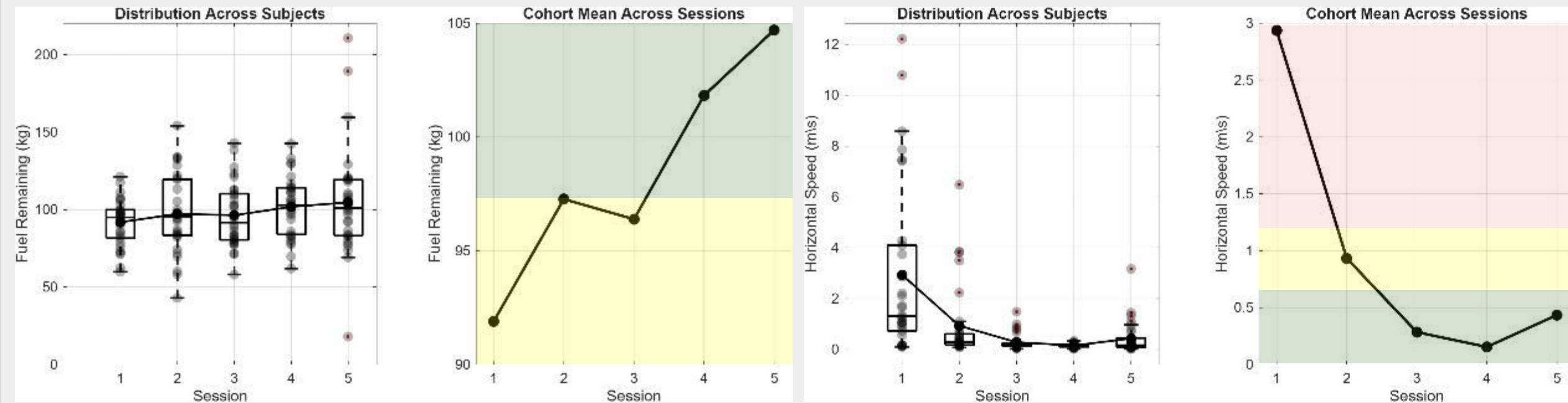
- Most learning occurred between sessions 1-4
- Reduction in performance after 4-months of non-use. Guidance recommendation = 1m/s at touchdown



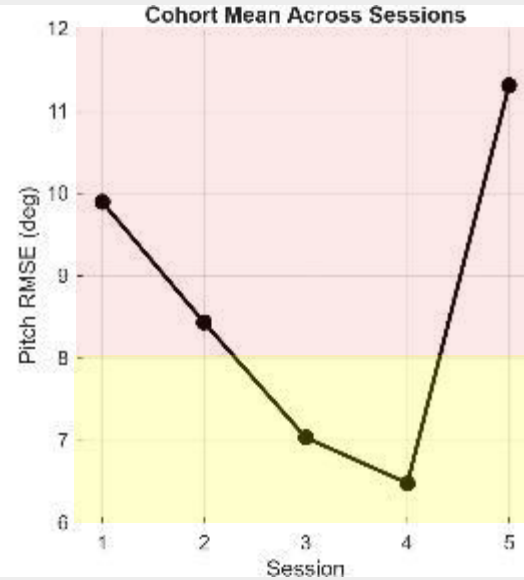
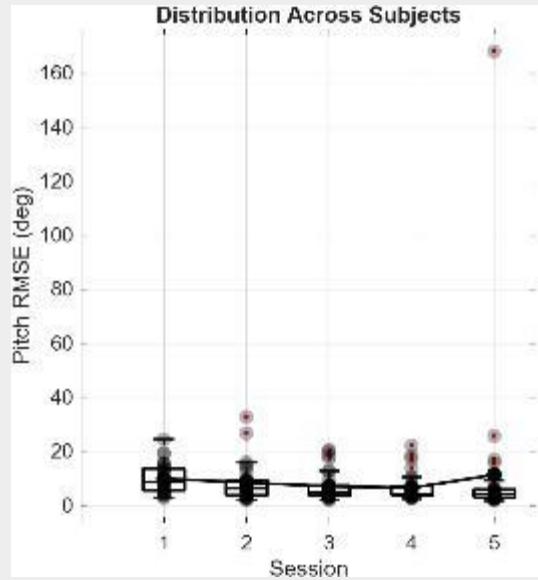
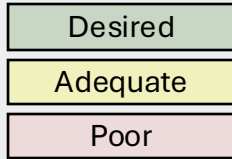
Touchdown Performance – Fuel Remaining & Horizontal Speed

- On average, fuel remaining within the desired threshold was achieved at session 4
- Horizontal speed at touchdown improved from sessions 1 – 4 and increased slightly on session 5 while remaining within the desired threshold

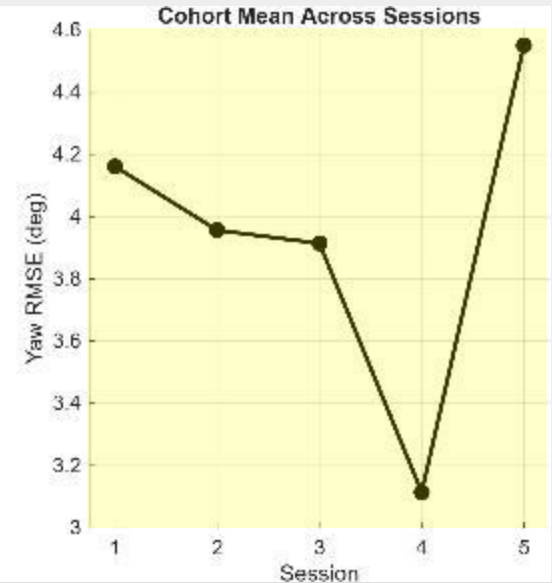
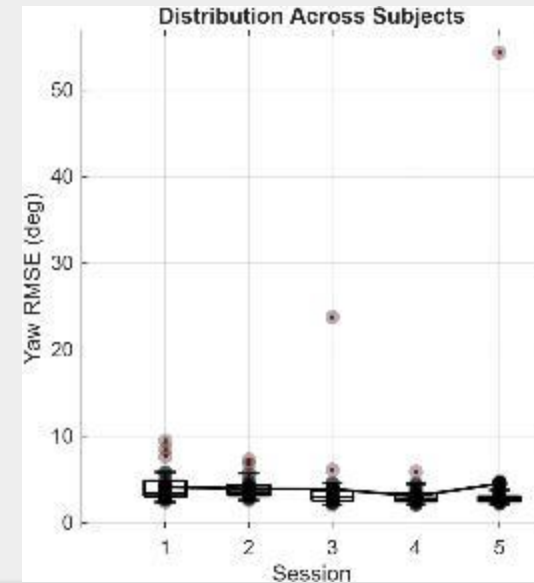
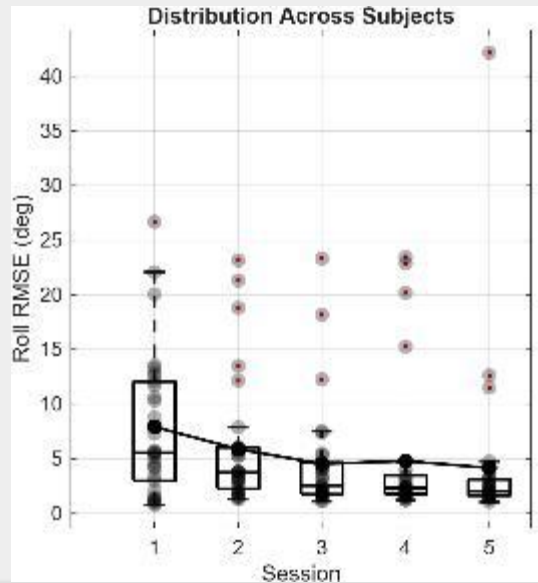
Desired
Adequate
Poor



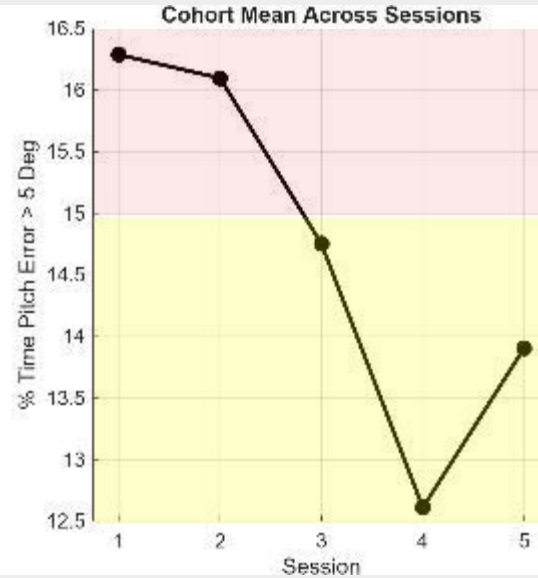
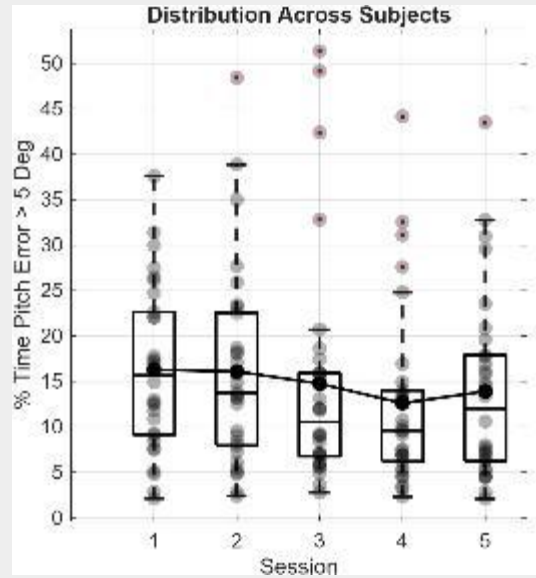
Manual Piloting Performance – Deviation from Guidance



- Steady improvement in pilot's ability to follow guidance across session 1-4 in pitch, roll, & yaw
- After 4-month hiatus in use of the system, pilots struggled to track guidance particularly in the pitch axis

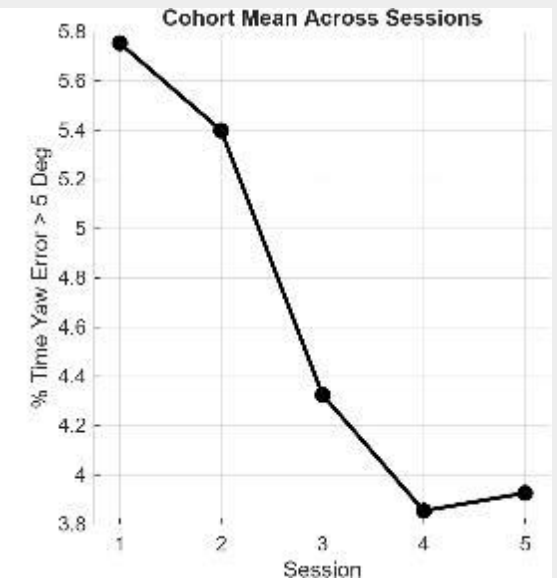
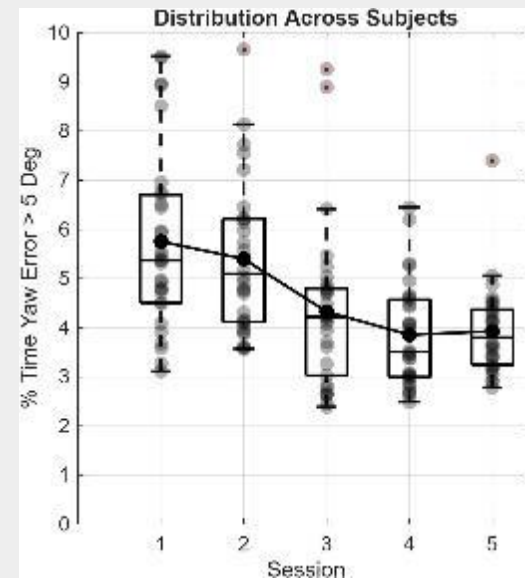
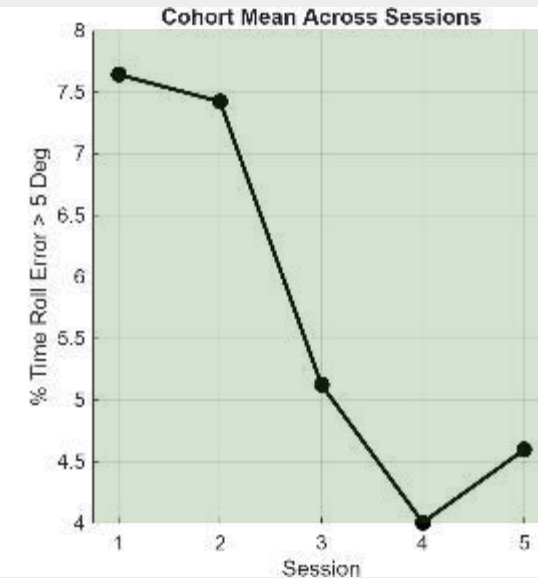
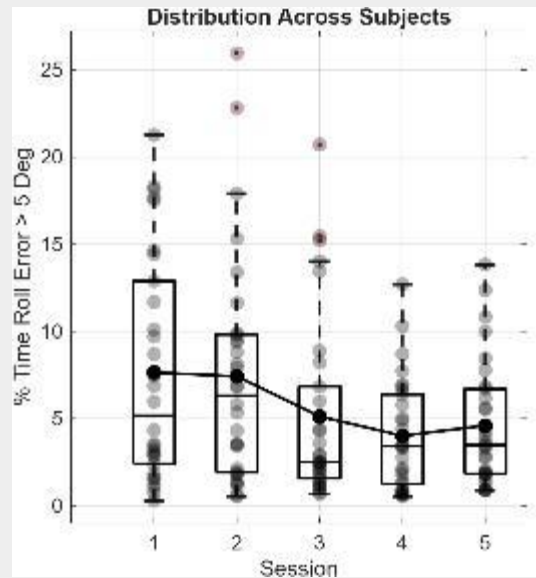


Manual Piloting Performance - % Time > 5 Deg Offset from Guidance



- Manual flight time ≈ 3 min, 13% ≈ 25 seconds error > 5 deg from guidance
- While the cohort mean suggests adequate/poor tracking, there are a subset of pilots who followed the guidance indicator very well
- Session 5 suggest a slight reduction in the pilot's ability to follow guidance recommendations for the vehicle attitude

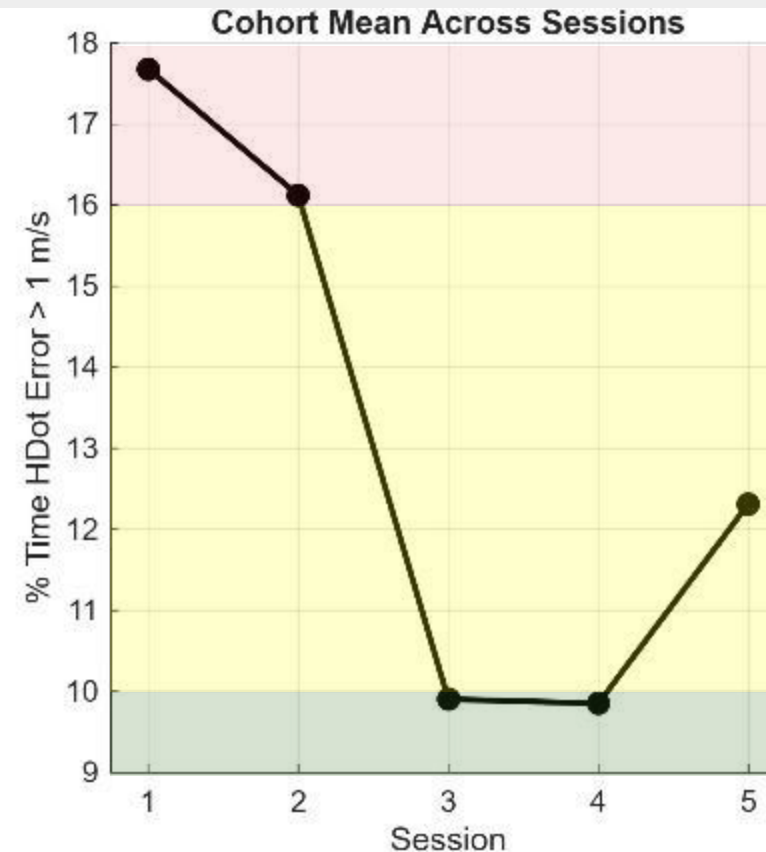
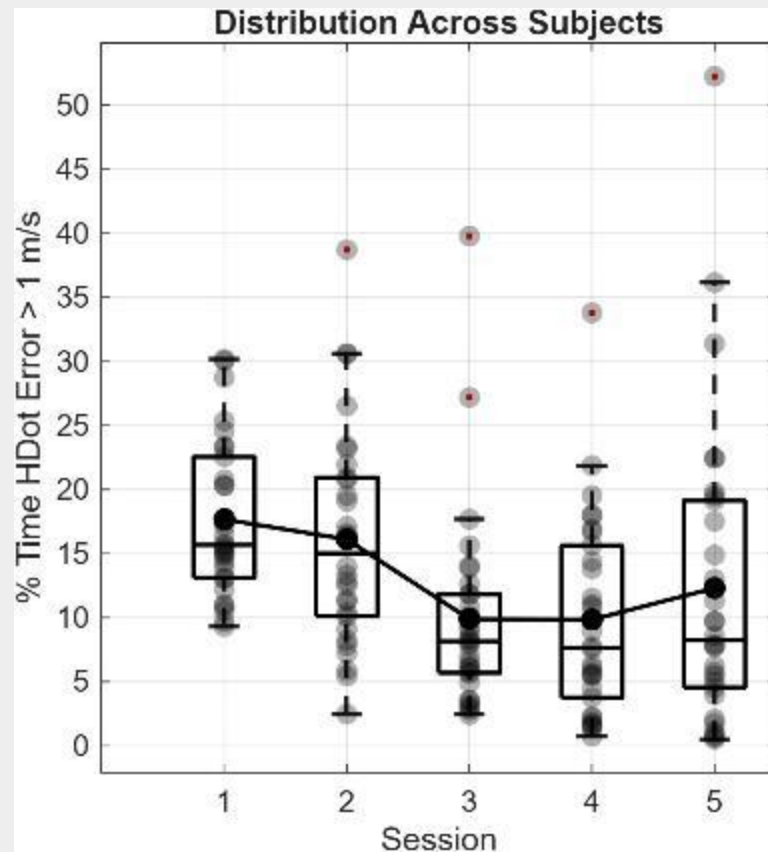
Desired
Adequate
Poor



Manual Piloting Performance - % Time > 1m/s from Guidance

- Manual flight time ≈ 3 min, 10% ≈ 20 seconds error > 1 m/s
- While the cohort mean suggests adequate tracking, there are a subset of pilots who consistently followed the guidance indicator
- Session 5 suggests an average five-second increase in sink rate offset from guidance across the 12 trials within this session

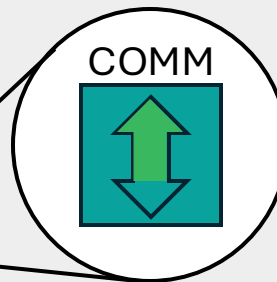
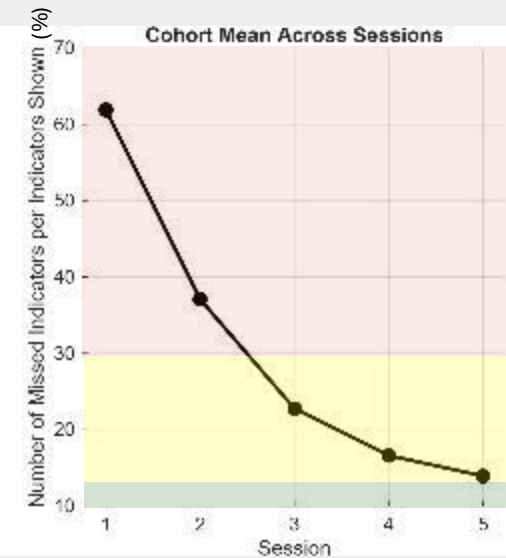
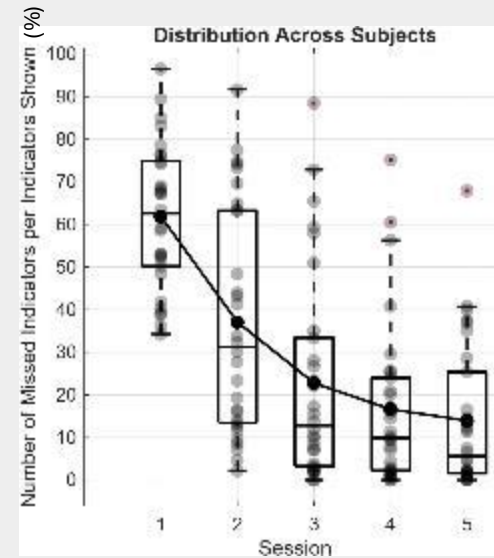
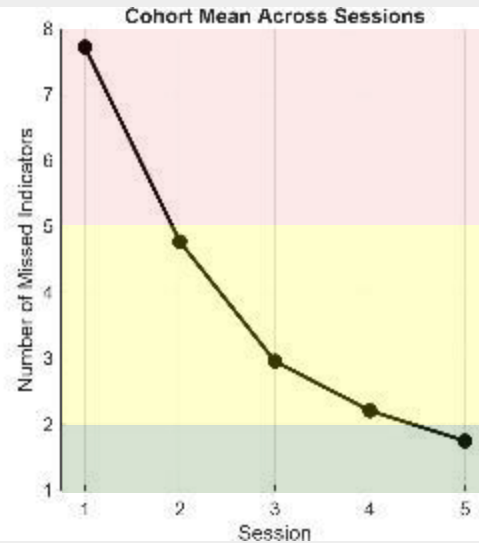
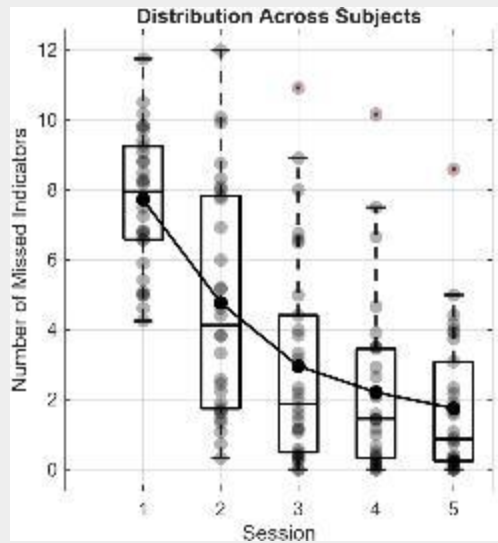
Desired
Adequate
Poor



Dual Tasking Performance – Number of Missed Indicators

- Results suggest a steady learning progression in the pilots' ability to monitor the secondary workload task across all five sessions
- Even after not using the sim for 4 months, many pilots improved the execute of this secondary task by missing less indicators
- Pilots commonly missed indicators during dynamic portions of the trajectory (i.e., during manual takeover to redesignated landing target and during a heading update which required yaw input on the RHC)

Desired
Adequate
Poor



Forward/Up
Backward/Down



Manual Control Summary

- **Evidence of continued learning across sessions**
 - Most performance metrics showed significant improvement with training
- **Variable time to proficiency across metrics**
 - Some metrics reached criteria by **Session 1–2**, others required **up to Session 3**
- **Overall retention maintained after 4-month gap**
 - No significant degradation in median performance for most measures
- **Partial skill decay in select domains**
 - Some metrics showed reduced proficiency, indicating **differential retention**
- **Initial performance drop at retention session**
 - Several participants failed the first trial and required additional attempts to recover
 - Highlights importance of **skill recency and just-in-time training**

Gaze Tracking Areas of Interest

Out-the-window views

ADI

Hazard Map

Heading

Altitude/ROD

COMM

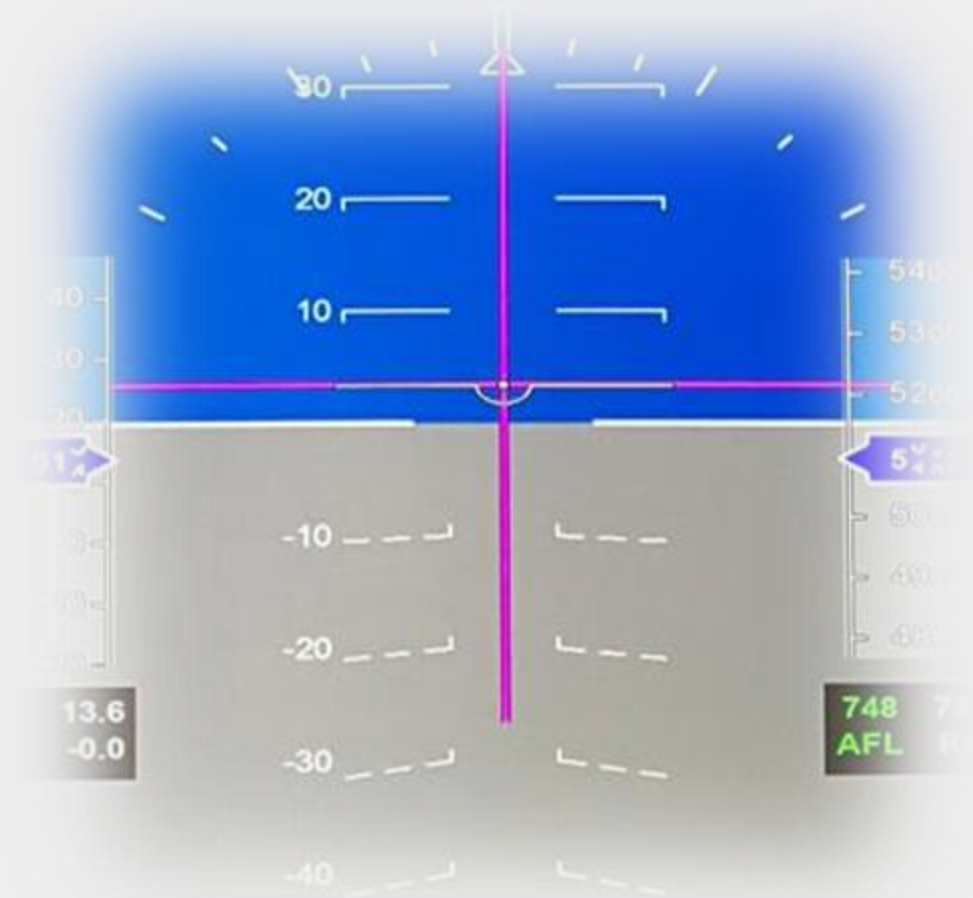
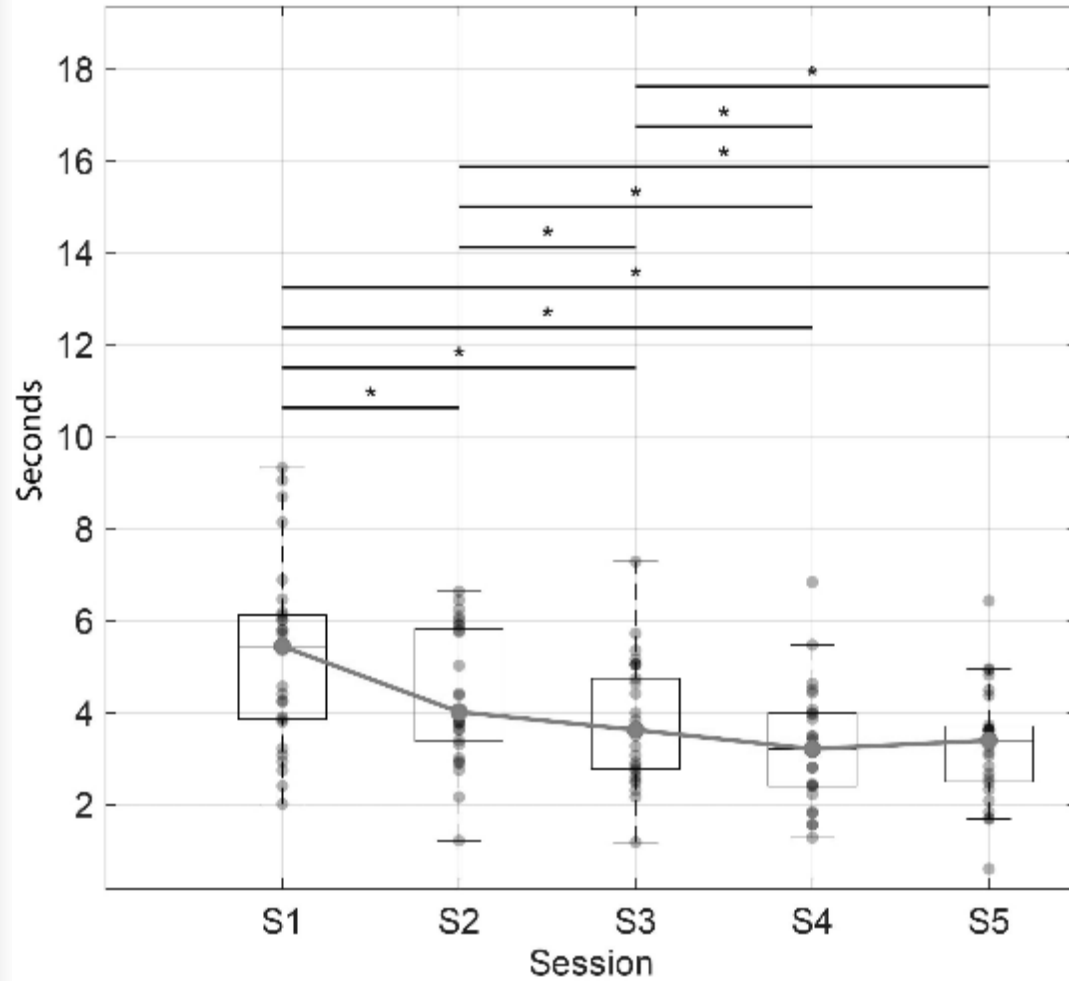


Tobii Heat Map

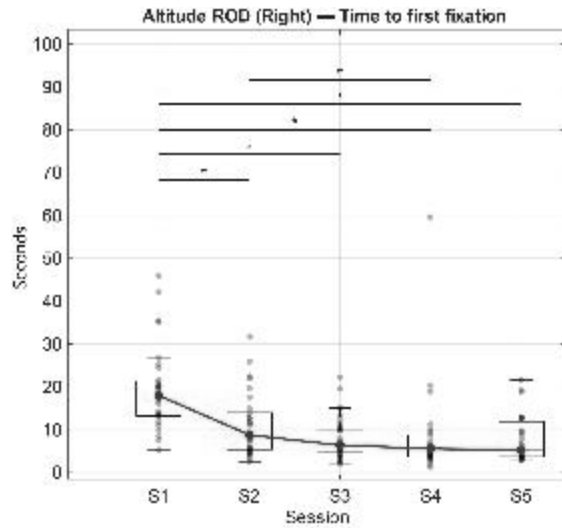
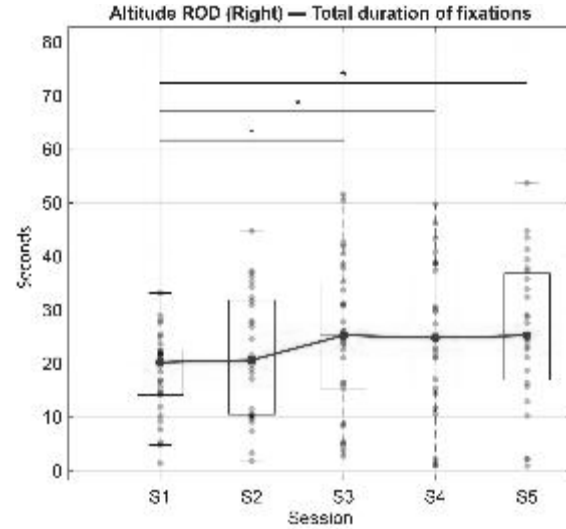
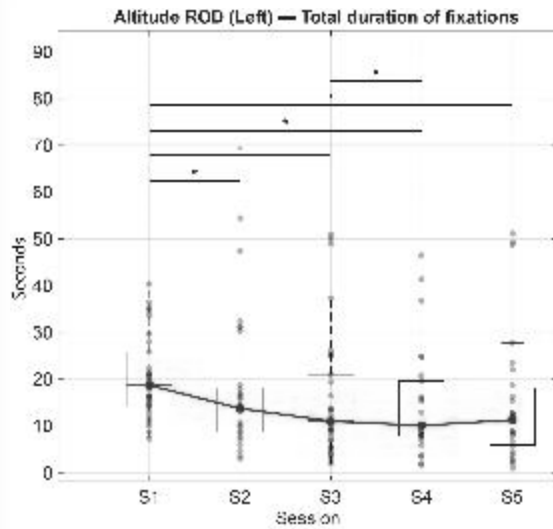
Place holder for gaze tracking video

Attitude Director Indicator (ADI)

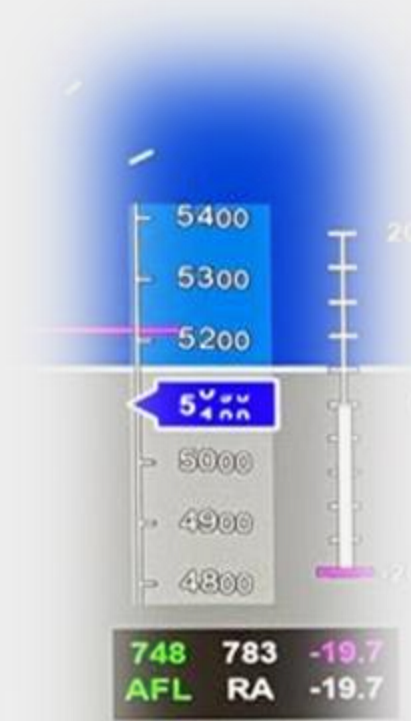
ADI — Maximum duration of fixations



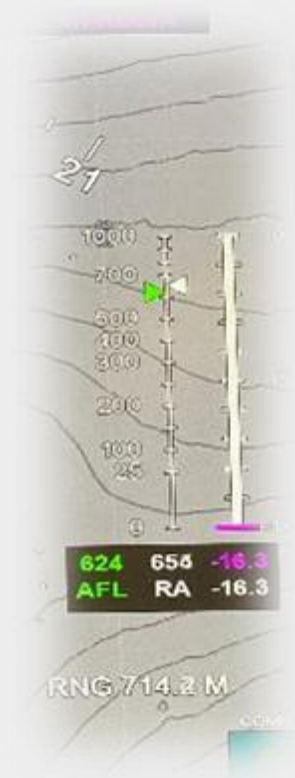
Altitude and Rate of Descent (ROD)



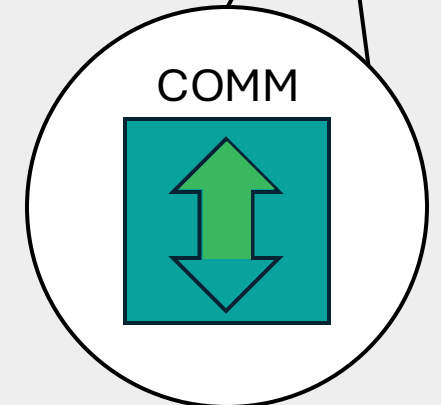
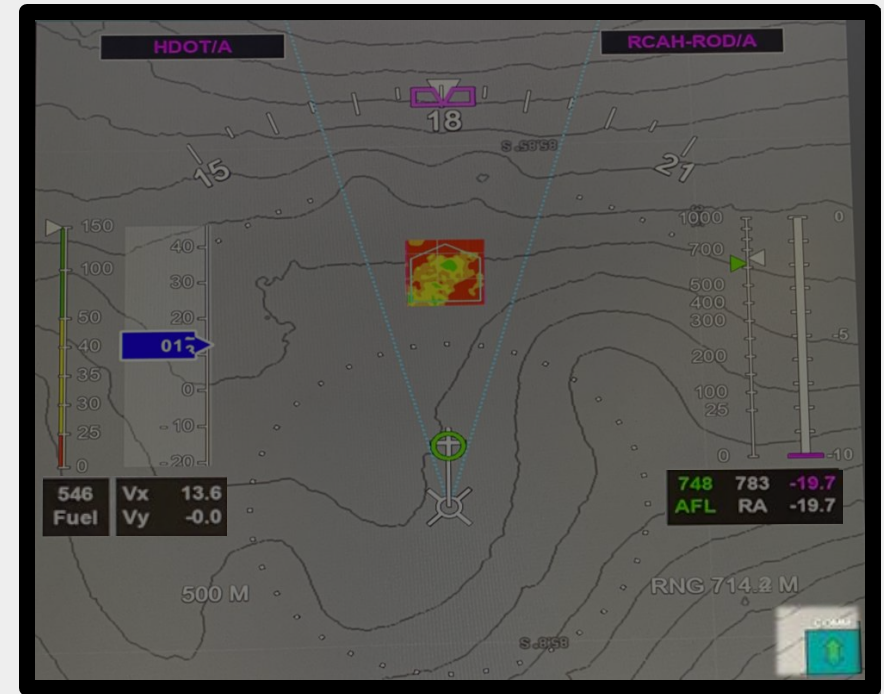
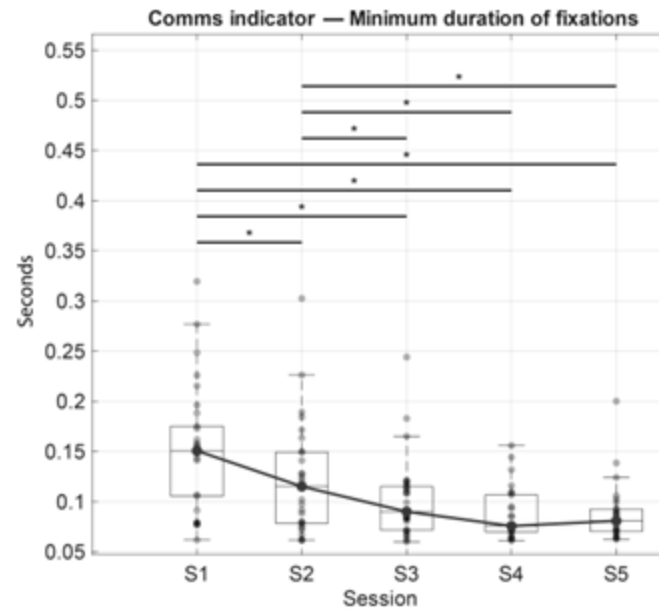
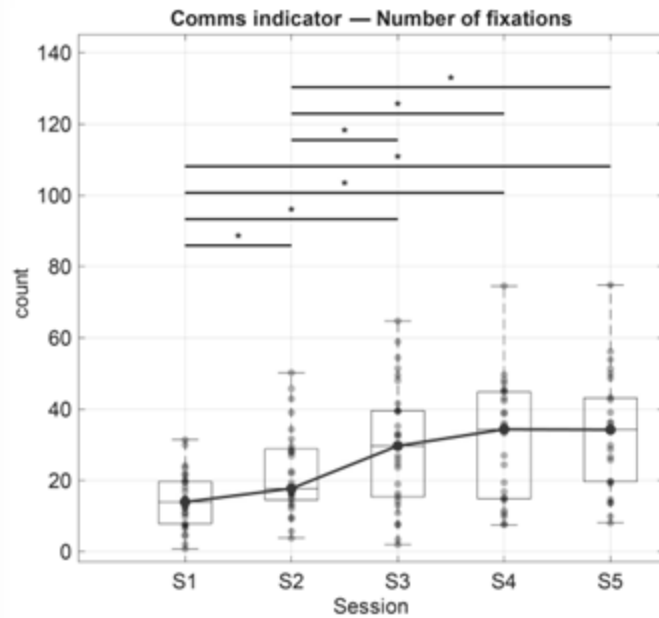
Left



Right

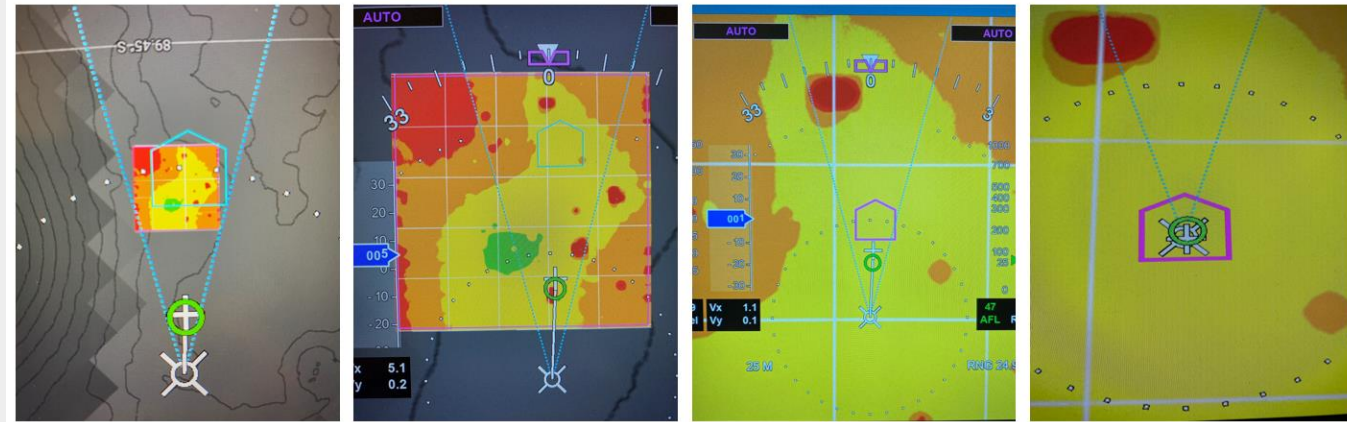
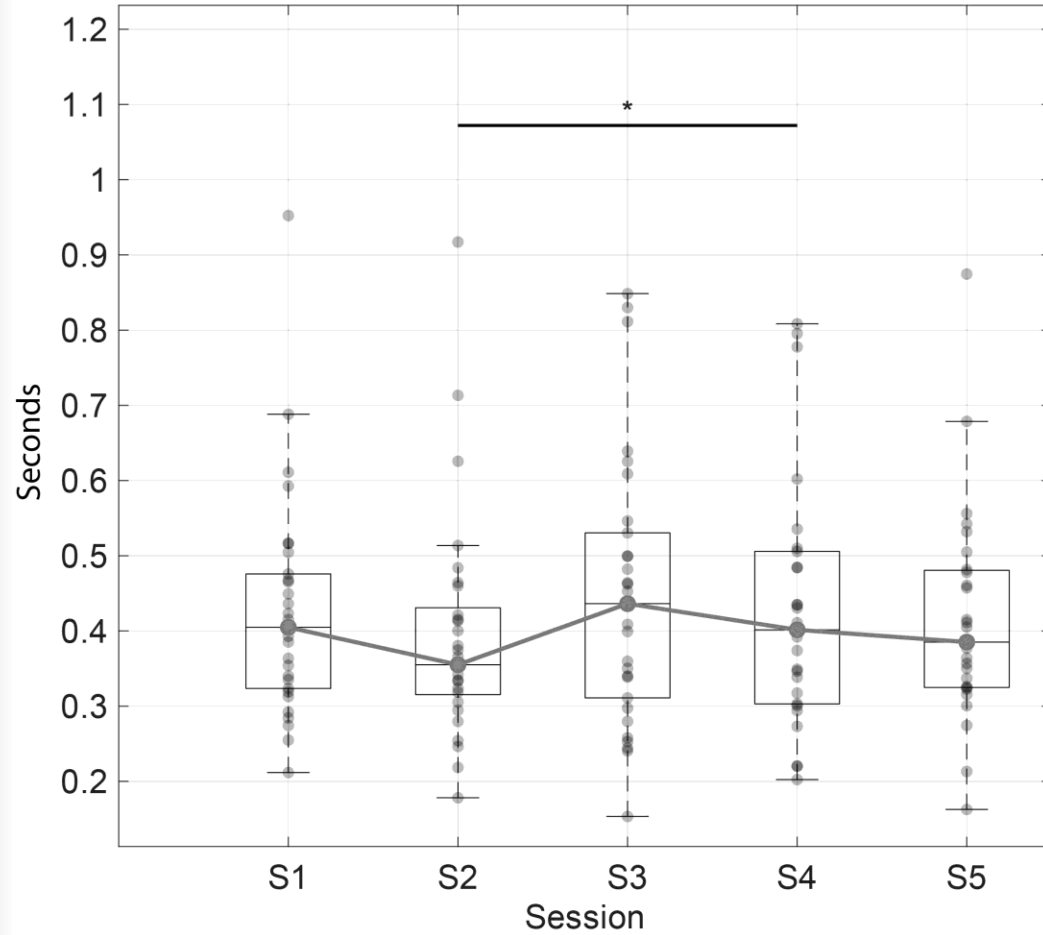


Communications Indicator

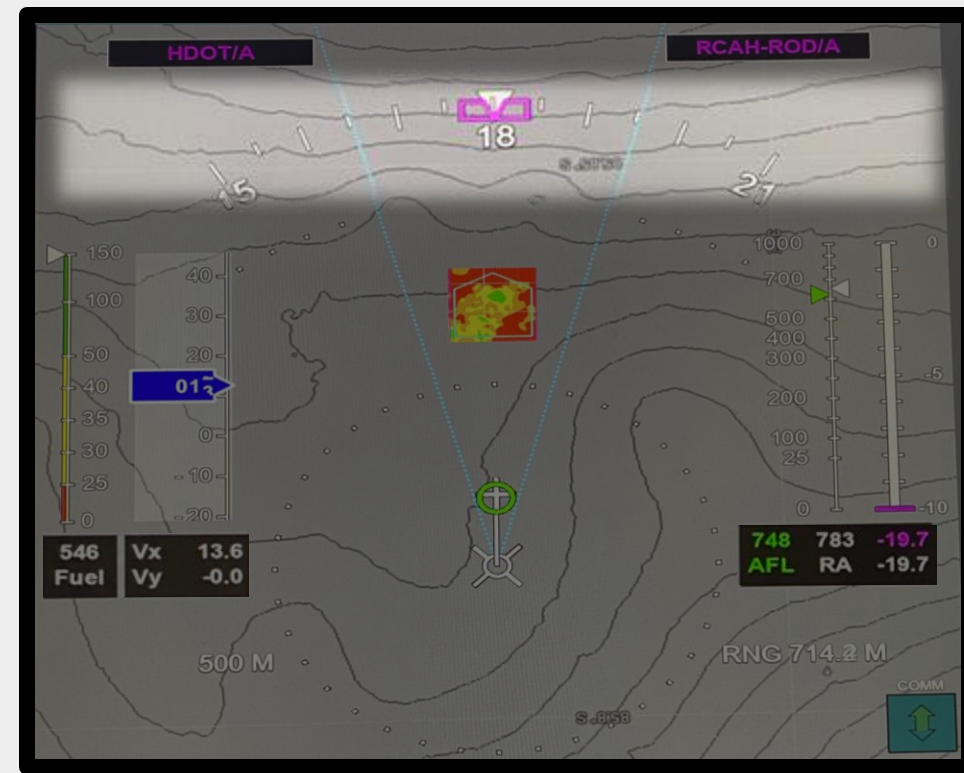
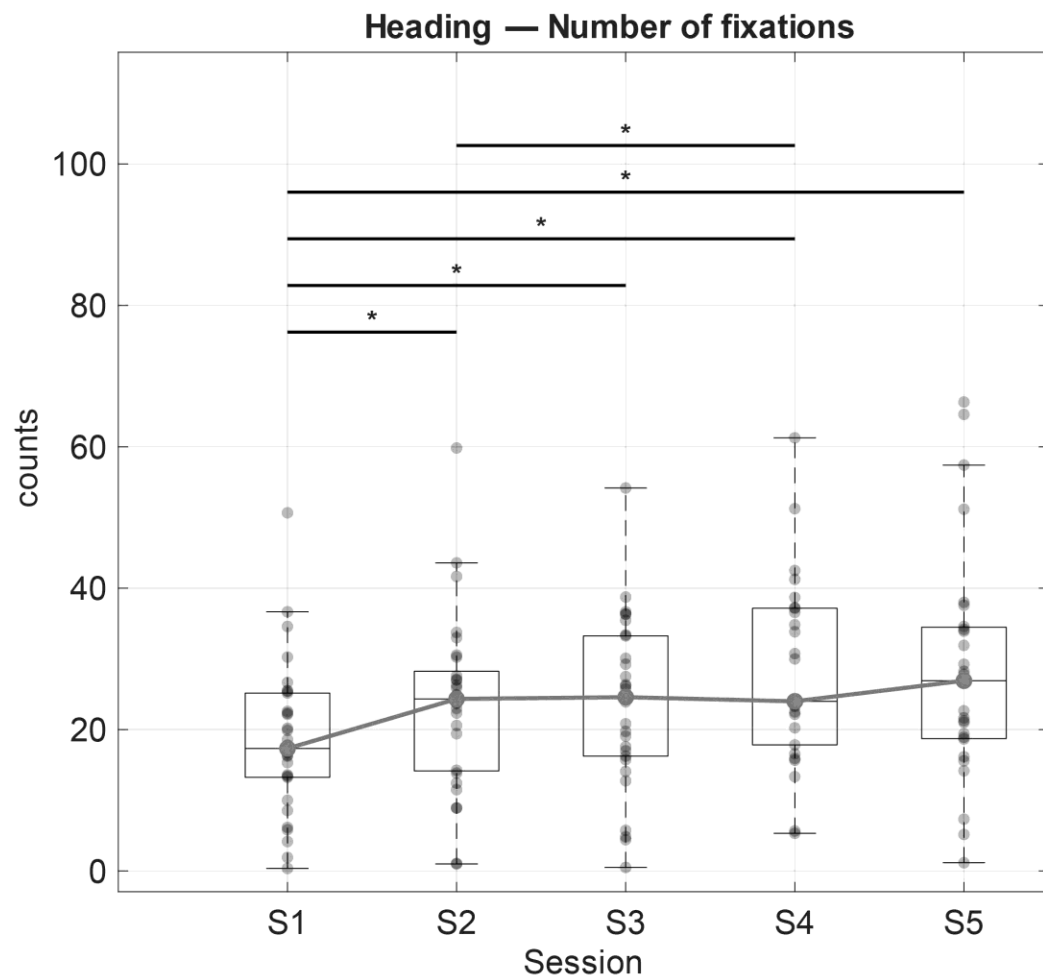


Tobii Metrics

Hazard map — Average duration of fixations



Tobii Metrics



Assessment Task for Lunar Approach Supervision (ATLAS)

Planned automated supervisory control

- Monitor automatic flight trajectory
- Determine if landing location is the original target location and monitor safety of location (i.e., hazards, slope)
- Simultaneously monitor system displays and warnings requiring pilot input (dual tasking)

Camera Configurations

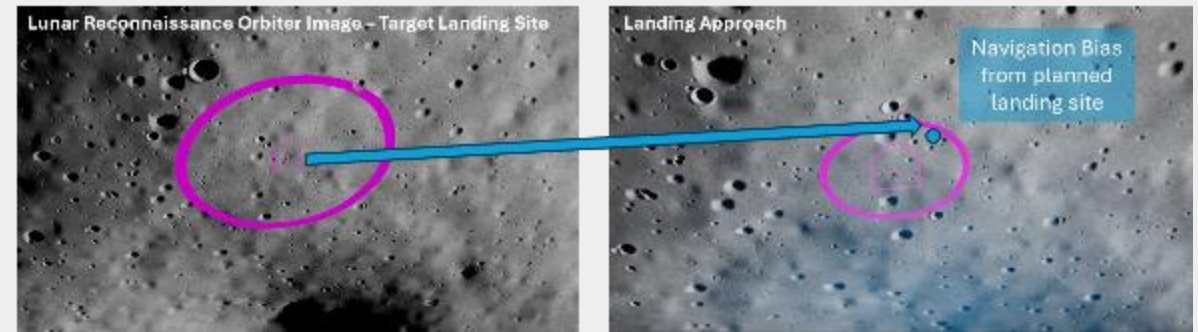
Fixed Camera



Gimbaled Camera

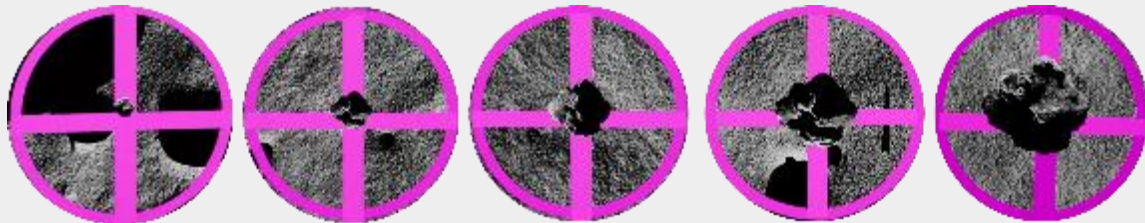


Navigation Bias

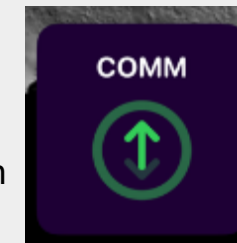


Dual Tasks

Landing Hazards (rocks/boulders) 1 – 5 m diameter



Swipe
interaction



Tap
interaction

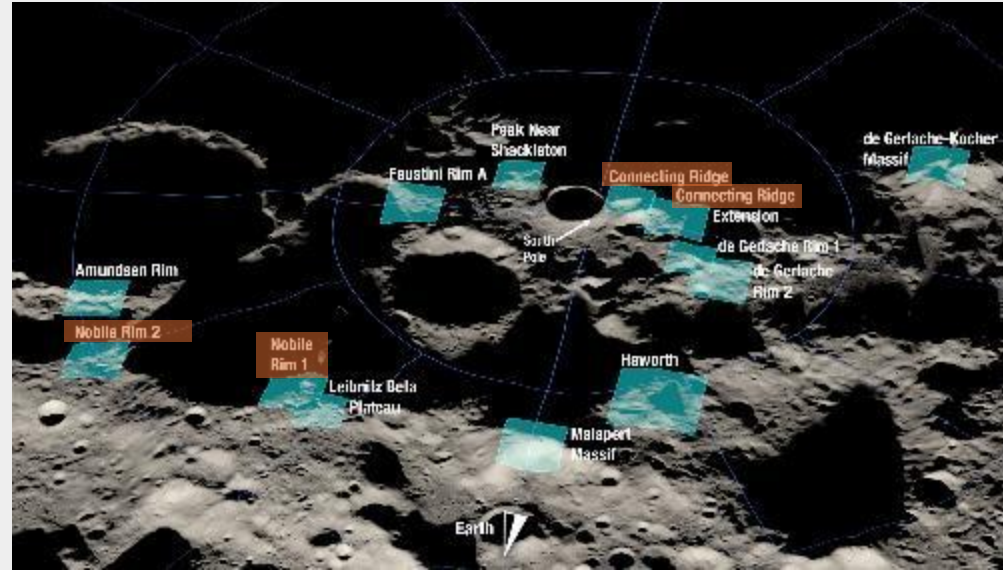
ATLAS Trials Scenarios and Session Loadouts

Trial Parameters

- Hazards (0 – 5 m)
- Landing sites (6; Connecting Ridge and Nobile Rim sites)
- Sun azimuth (0, 90, 180, 270 deg)
- Navigation downrange and cross range bias (0 or 25 m)
- Glide slope (45 deg)
- Altitude (1200 m) and downrange (1200 m)
- Camera modes (fixed and gimbal)
- Dual task difficulty (easy, hard)
- Various lighting conditions (dates and time of day)

Six scenario types (30 scenario combinations)

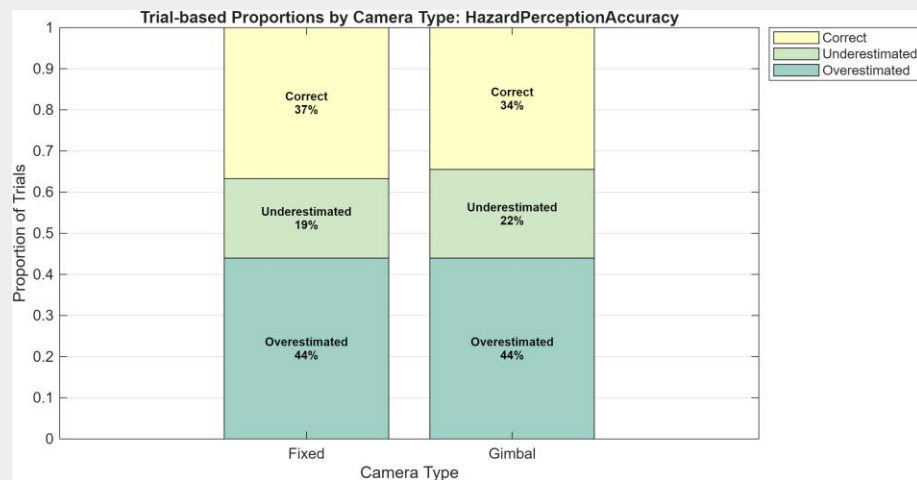
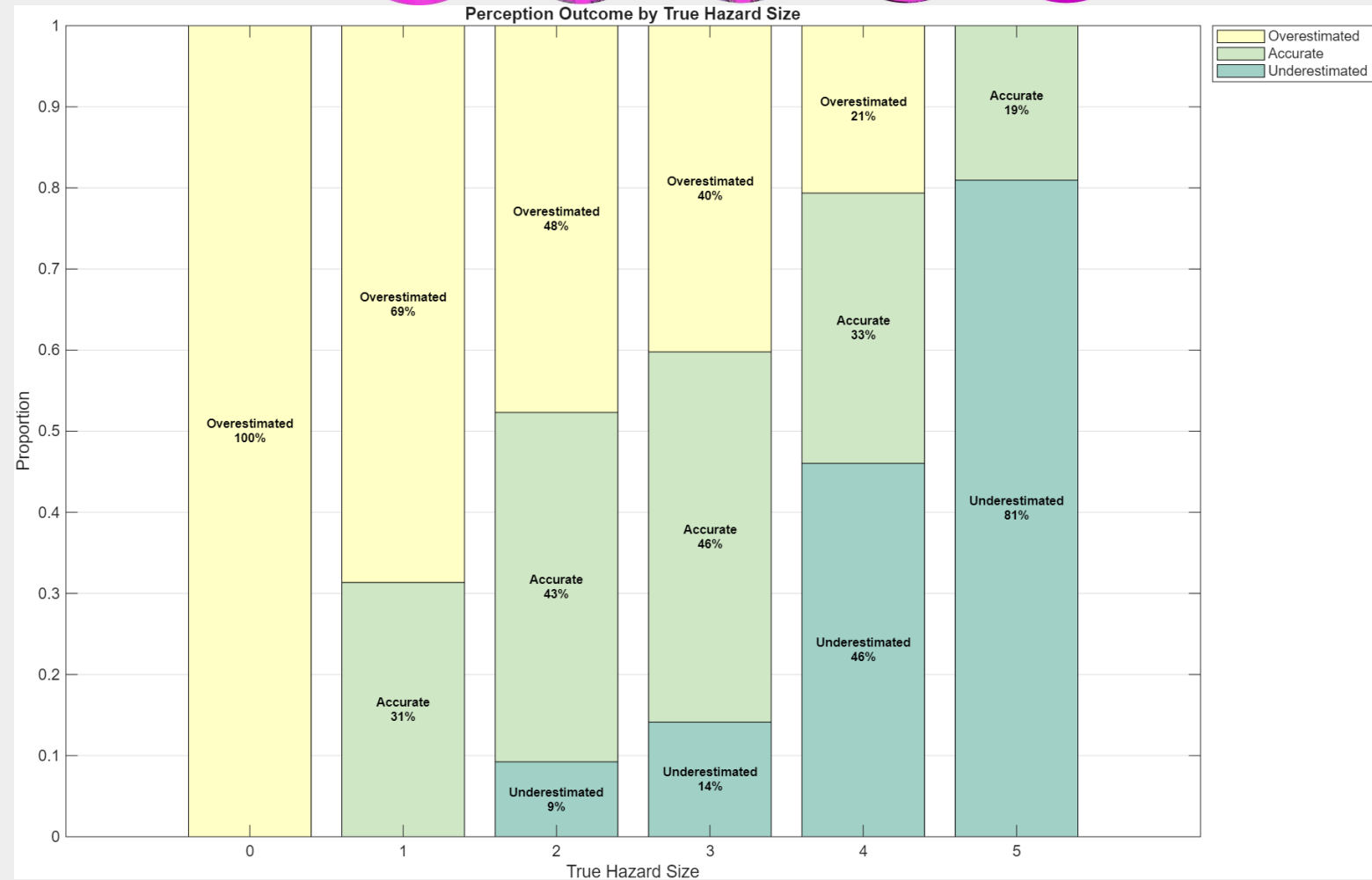
- **Diversion Requirement**
 - No divert required [1 of 6 trials]
 - Diversion required [5 of 6 trials]
- **Camera Configuration**
 - Fixed [3 of 6 trials]
 - Gimbal [3 of 6 trials]
- **Navigation Bias**
 - Yes [3 of 6 trials]
 - No [3 of 6 trials]
- **Hazards**
 - Yes [4 or 5 of 6 trials]
 - No [1 or 2 of 6 trials]



Place holder for video of ATLAS

Hazard Perception

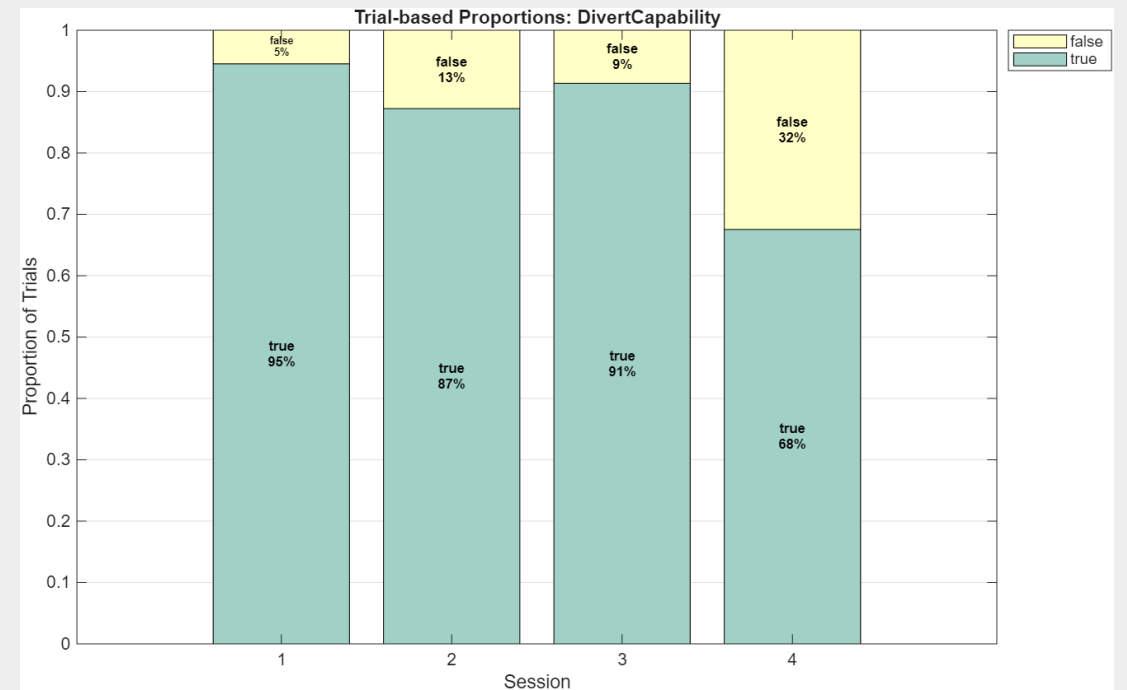
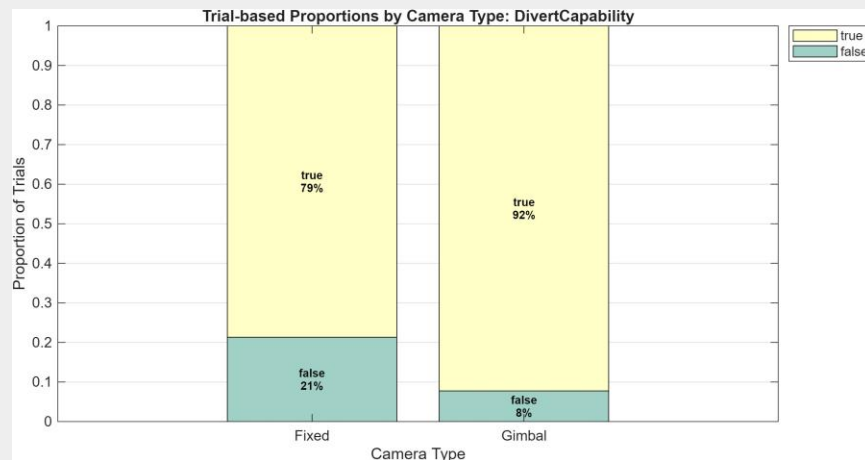
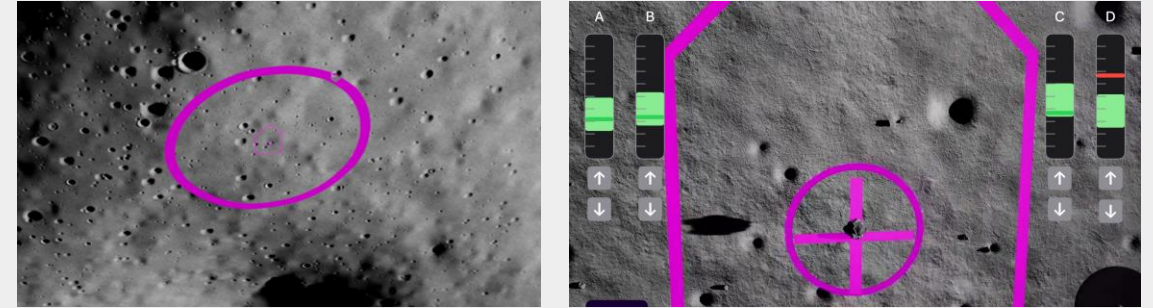
- **Small hazards** were frequently **overestimated**
- **Large hazards** were **underestimated**
- Accuracy peaked at the mid-range hazard size (3), suggesting participants anchored judgments near the center of the response scale
- Pattern may reflect **perceptual uncertainty**, where participants default toward a middle estimate when **hazard size cues are ambiguous**
- **Camera configuration** does not meaningfully improve hazard size estimation



Operational implication: large hazards may be perceived as smaller than they are, which could influence diversion decisions during supervisory control landing tasks

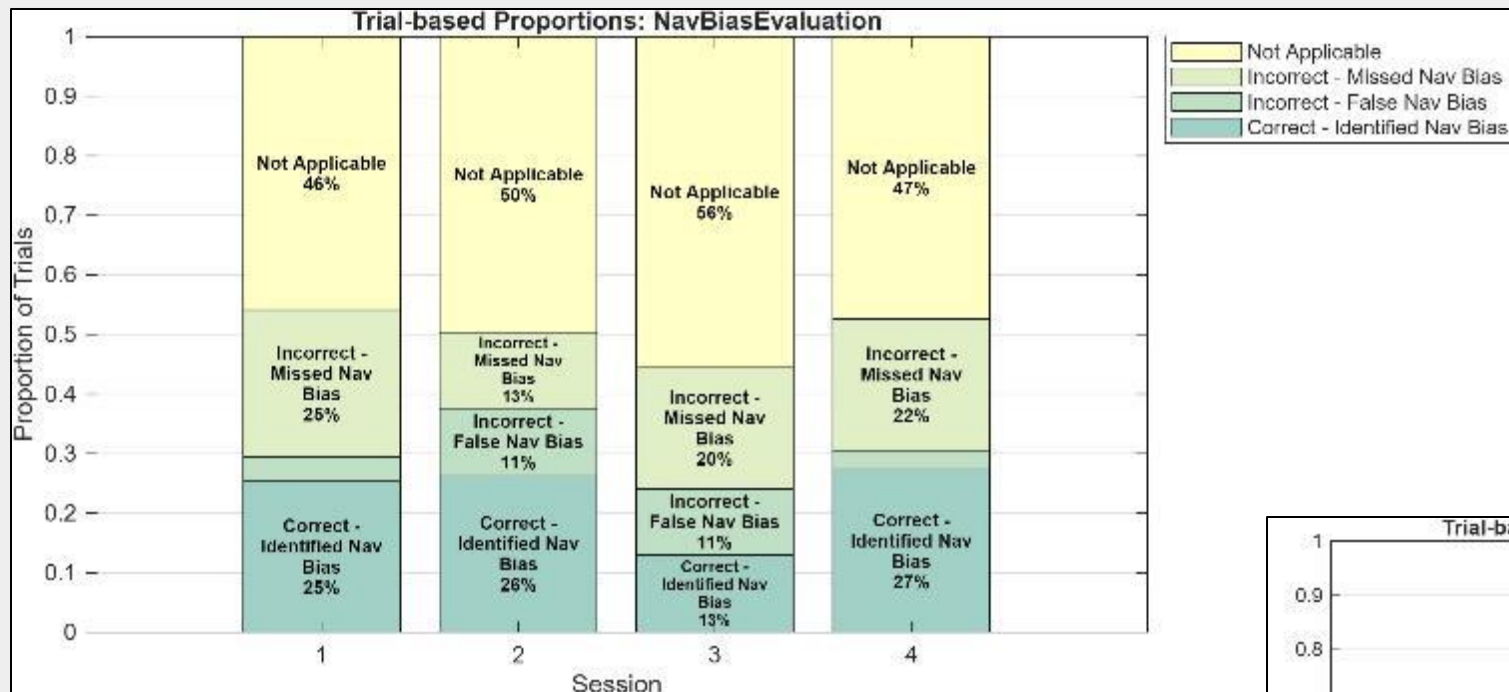
Divert Decisions within Vehicle Capability

- Divert decisions were correct in the majority of trials in all sessions, indicating generally strong capability to assess within-vehicle limits
- Session 1 shows the **highest accuracy** (~95%), suggesting **strong initial understanding** with training support
- Marked drop in accuracy (~68%) and increase in incorrect decisions (~32%) on session 4
- Indicates **degradation in retained decision-making ability** over time without practice
- Unlike hazard perception, divert capability shows a **sensitivity to camera configuration**



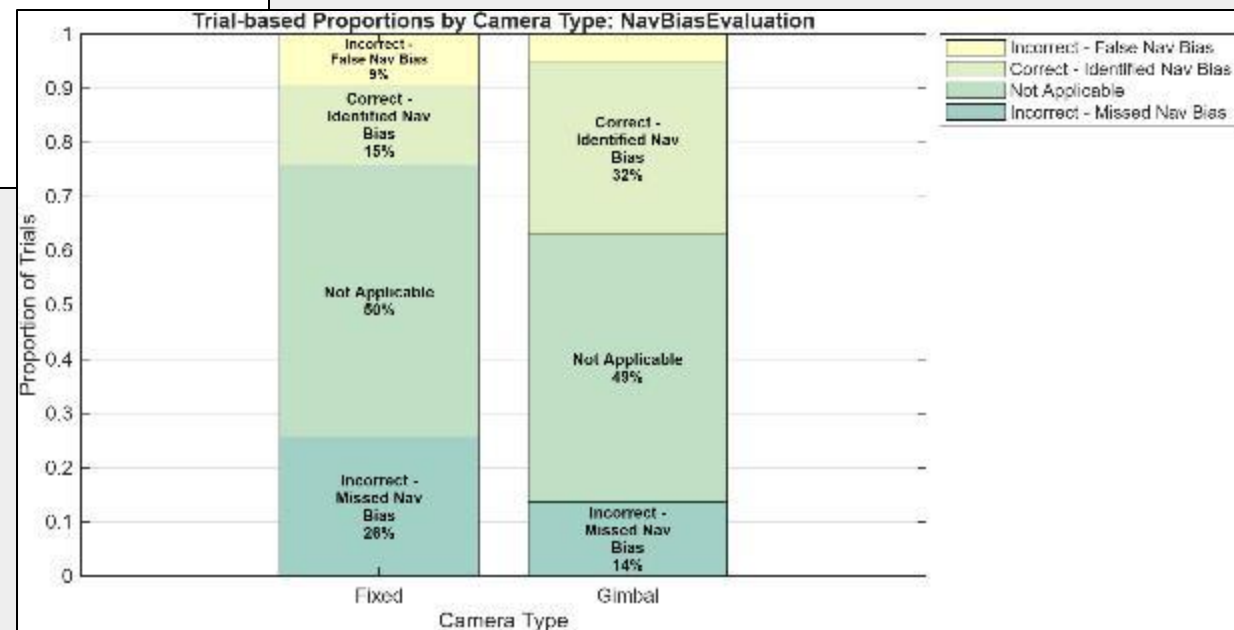
Operational implication: divert decision accuracy is generally high but degrades over time without practice and is sensitive to camera configuration, highlighting the need for refresher training and optimized viewing systems to maintain reliable assessment of vehicle capability.

Navigation Bias Perception



Operational implication: gimbal-enabled viewing provides a clear performance advantage in detecting navigation bias, reducing the likelihood of undetected errors and improving decision reliability.

- **Missed nav bias** consistently **higher** than false alarms. Indicates a **tendency to under-detect navigation bias**
- Correct identification remained relatively low (~13–27%) across sessions. No steady improvement across sessions
- Clear improvement with gimbal camera. Correct identification increases from: **15% (Fixed) → 32% (Gimbal)**

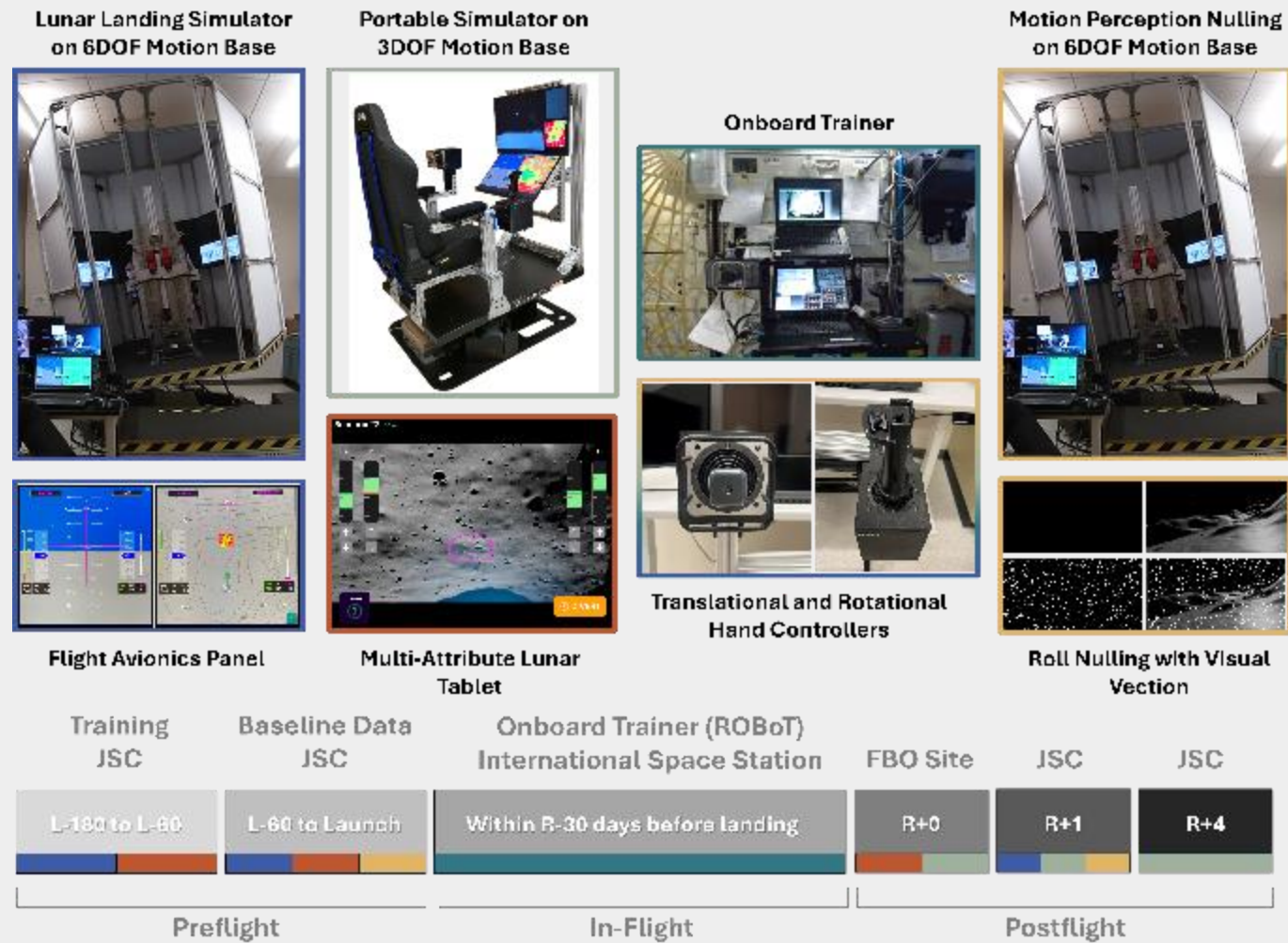


Supervisory Control Summary

- **Decision-making improves with enhanced viewpoints**
 - Gimbal camera significantly improves **divert decisions and navigation bias detection**
- **Perceptual limitations persist despite sensor improvements**
 - Hazard size estimation remains **low accuracy and biased**, unaffected by camera type
- **Primary risk driver is missed information, not false alarms**
 - Participants are more likely to **miss hazards or navigation bias** than over-report them
- **Training drives strong initial performance, but retention is variable**
 - Most skills are retained after delay, but **some degradation occurs without practice**
- **Performance is task-dependent**
 - Higher-order decisions (divert, bias detection) benefit from improved context
 - Lower-level perception (size estimation) remains constrained

Next Steps

1. Characterize the *impact of spaceflight* on crew capability to perform *manual crew override* of a simulated lunar landing vehicle
 - Short duration Private Astronaut missions
 - Long duration ISS missions
2. Examine how measurements in *vestibular* and *cognitive function* relate to proficiency during supervisory manual control and crew override.
3. Compare performance during *on-board just in time training* late in-flight with landing tasks conducted early in the *postflight period*
4. Evaluate assessments of performance in healthy *ground control subjects*
 - Shadow control subjects (within ± 5 years age range and the same sex as crew)



Thank you

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