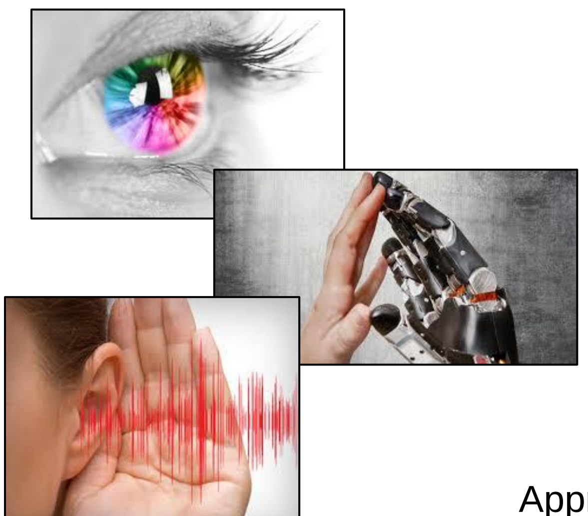
Cueing Research by the US Army Aeromedical Research Laboratory



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Major References

Study 1: USAARL Report 2016-10, Pilot Cueing Synergies for Degraded Visual Environments by Russell, D., Statz, J.K., Ramiccio, J., Henderson, M., Still, D., Temme, L., Ranes, B. Crowley, J., and Estrada, A.

Study 2: USAARL Report 2017-04, Integrated Cueing Environment Testing: Pilot Cueing Synergies for Degraded Visual Environments by McAtee, A., Russell, D., Feltman, K., Swanberg, D.E., Statz, J.K., Ramiccio, J., and Harding, T.H.

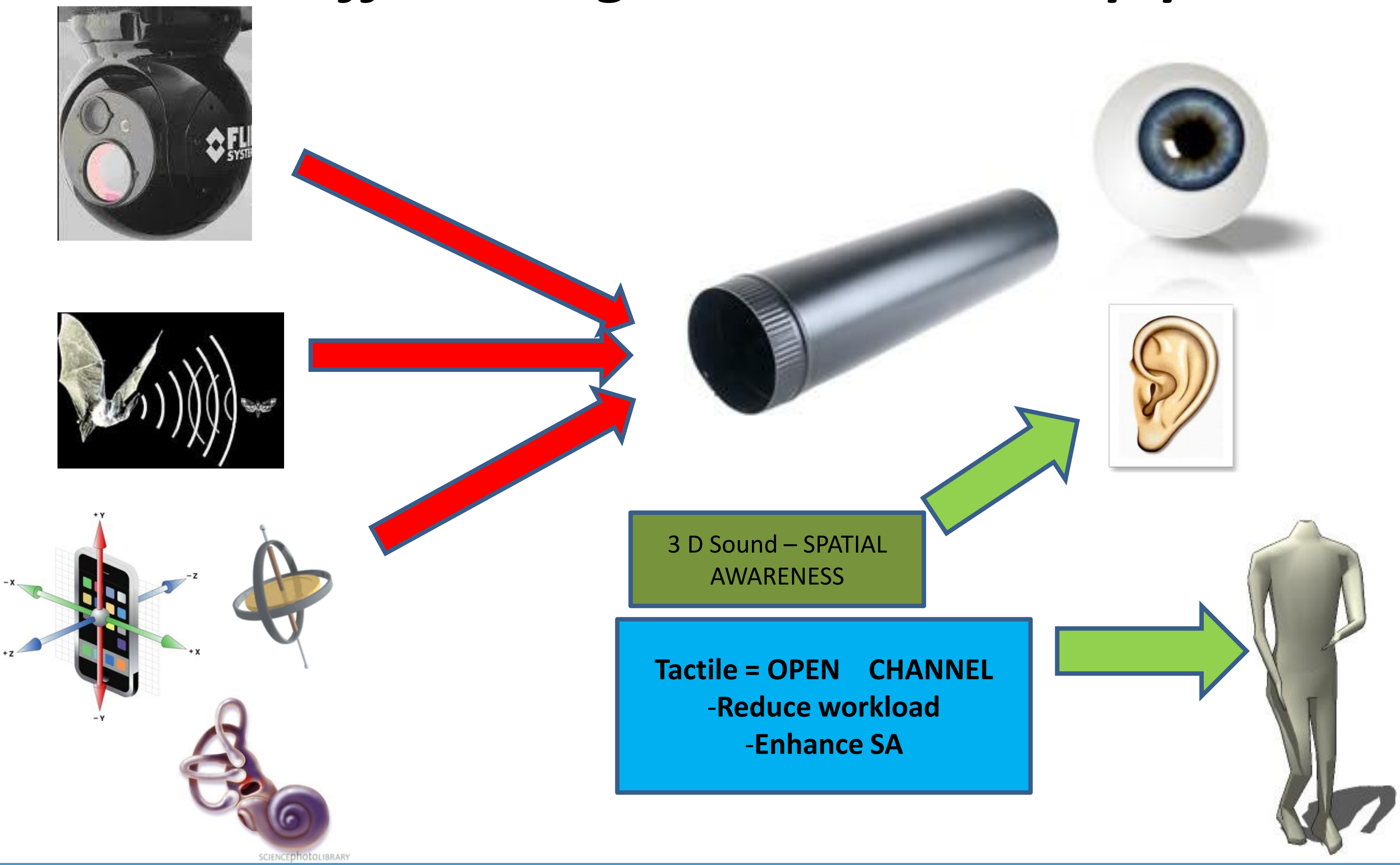
Introduction

- Vision is primary source of orienting information
- Reliance on visual cockpit displays to provide
  - Somatogyral
  - Somatogravic
  - Audio
  - Spatial Information
- Results in high visual and cognitive workloads

Introduction (cont.)

- Overreliance on any one sensory channel during high workload can result in
  - Cognitive tunneling
    - Intense focus causes loss of awareness of environment as a whole (incomplete picture)
  - Sensory bottleneck
    - Cluttered displays cause delays and distraction
    - Longer search times impact performance
    - Congested/complex displays can cause pilots to see and comprehend less as more information is provided

"off-loading the visual stovepipe"



Introduction (cont.)

- Interest in multimodal interfaces has increased
- Multiple Resource Theory (MRT)
  - predicts that performance can be improved by distributing information across sensory channels
  - humans are capable of processing compatible information from multiple sensory sources in parallel
  - multimodal approach that utilizes visual, audio, and tactile senses may provide information for safe DVE operations and prevent overreliance on the visual sense

USAARL's History in Cueing-Related Studies

- Rich history of assessing visual displays and optical systems
- Tactile cueing: Tactile Situation Awareness System (TSAS) – since 1996
- 3D Audio studies – since 2004
- Recent studies have evaluated tactile and 3D audio synergies for target localization

DVE Cueing Studies

- Goal of USAARL cueing research is to optimize sensory cueing to the pilot
  - Compatibility
  - Benefit
  - Conflict
- Sponsor: US Army Research, Development, and Engineering Command - Rotorcraft DVE Mitigation Program
  - Systematic approach to evaluating cueing displays
- Purpose of USAARL simulator studies is to aid in the selection and integration of cueing displays to facilitate helicopter operations in DVE

DVE Cueing Studies (cont.)

- Recent studies (limited distribution)
  - Temporal Latency Study to determine the performance optimization variables of visual displays
    - Latency is the time from when an object is sensed by a sensor until it is presented in the cockpit
    - Refresh rate is the rate at which the display refreshes its output
  - Field of View (FOV) Study to define the optimal FOV for specified displays

USAARL Capability for DVE Research

- Research staff - aviators, human factors experts, flight surgeons, psychologists, audiologists, optometrists, biomedical engineers
- NUH-60 Research Flight Simulator
  - Customizable cockpit to A, L, V, M models
  - Full-motion, full-visual, 6 degrees of freedom (DOF)
  - Environmental Control System (Hot/Cold)
  - 7 X-IG Image Generators (dedicated sensor IG)
  - Enhanced brownout/whiteout models
  - Flight and Biomedical Data Collection Systems (128 flight and 30 biomedical channels)
  - Tactile and aural cueing systems

USAARL STUDY 1: PILOT CUEING SYNERGIES FOR DEGRADED VISUAL ENVIRONMENTS

- Goal of the study was to determine if symbology/cueing sets:
  1. were compatible with each other;
  2. improved flight performance and reduced workload/stress;
  3. in different combinations, were effective as evidenced by subjective evaluations, flight performance, and workload/stress metrics; and
  4. varied as to their effectiveness with different flight tasks.

Study Plan

- Conduct simulator flight tests of the selected tasks under 12 combinations of the three different visual symbology sets and the two supplemental cueing technologies, head-down, using an IR display of the exterior view which was obscured by brownout conditions
- Flight tasks were derived from Aeronautical Design Standard (ADS)-33 test maneuvers: Approach to Landing, Approach to Hover, Hover, and Sidestep
- Evaluate the cueing set combinations using the test pilots' subjective ratings, flight performance, and biometrics (physiological measures of stress) as metrics of the cueing displays' performance

Overview

Task Order	Tasks
1	App/Land
2	App/Hover
3	Hover
4	Sidestep

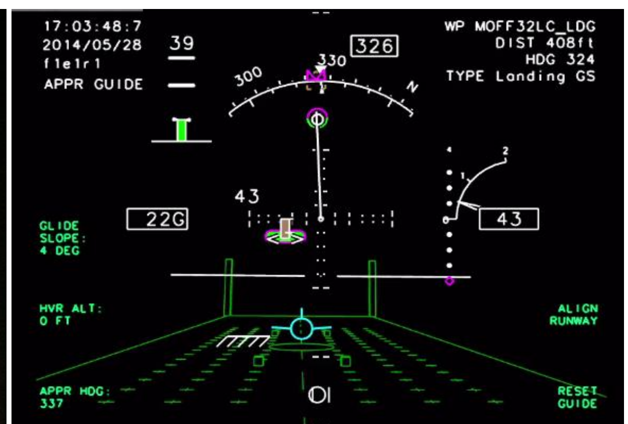
Visual Symbology Set	IR Scene	IR Scene + Tactile	IR Scene + Aural	IR Scene + Aural + Tactile
Legacy HUD	1	2	3	4
BOSS + 3D Conformal	5	6	7	8
FISH	9	10	11	12

- Derived ADS-33 selected tasks
- Scores
  - Subjective Measures
  - Pilot reports
  - Objective measures of flight performance
  - Biometric Data
- Test using Pseudorandomized Order
- Time Required
  - 16 hours per pilot (8 training/8 testing)
  - 8 pilots
  - 128 total hours

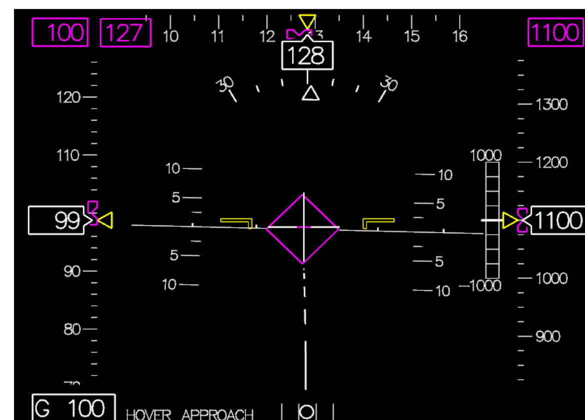
Flight Symbology

Real time Forward-looking Infrared (FLIR) imagery was paired with all displays.

Legacy (ANVIS 7)



BOSS

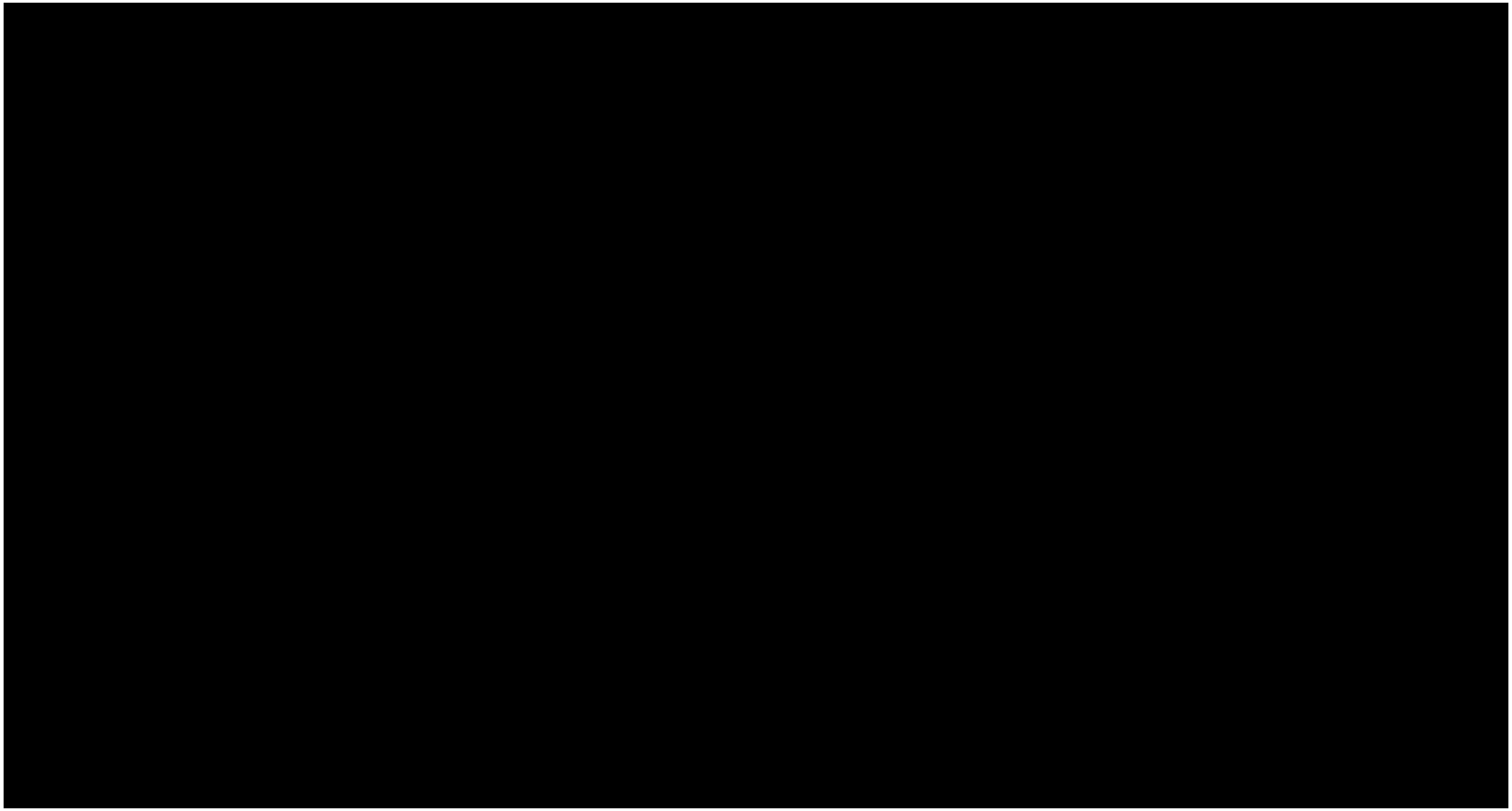


FISH

Tactile Cues

- TSAS provided to the pilot intuitive non-visual information to the pilot via their sense of touch
  - Altitude
  - Ground speed
  - Drift
  - Velocity vector

Tactile Cues



Aural Cues

<u>SwiftTalker Cues</u>

"Assume Guidance"

"Check Heading"

"Check Altitude"

"Check Speed"

"Altitude 100"

"Altitude 40, 30', 20', 10'"

"Left Drift, Right Drift,

Forward Drift, Aft Drift"

Flight Tasks and Standards:

Flight Tasks	
First	Approach / Landing
Second	Approach / Hover
Third	Hover
Fourth	Sidestep

Standards of performance:

Approach phase

Heading +/- 5° (040°) & Ground track alignment (minimal drift)
Altitude +7/-3 ' (250' AGL over changing terrain elevations)
Airspeed 80 KIAS (+/- 5 KIAS)

Landing phase

Heading +/- 5° (040°)
Airspeed not> 1-2 KTS Ground Speed
Touchdown Position Accuracy

Hover

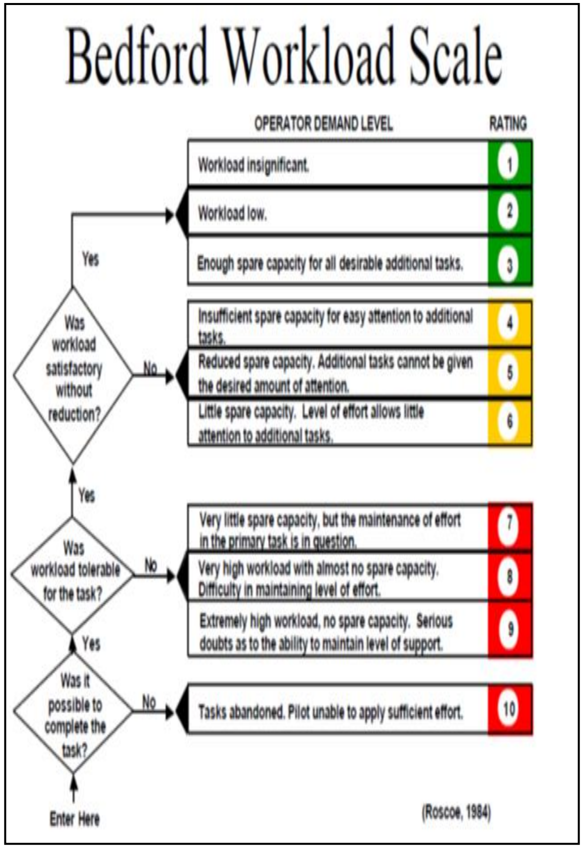
Heading +/- 5° (040°)
Altitude +/- 3 ' (30' AGL)
Position Accuracy

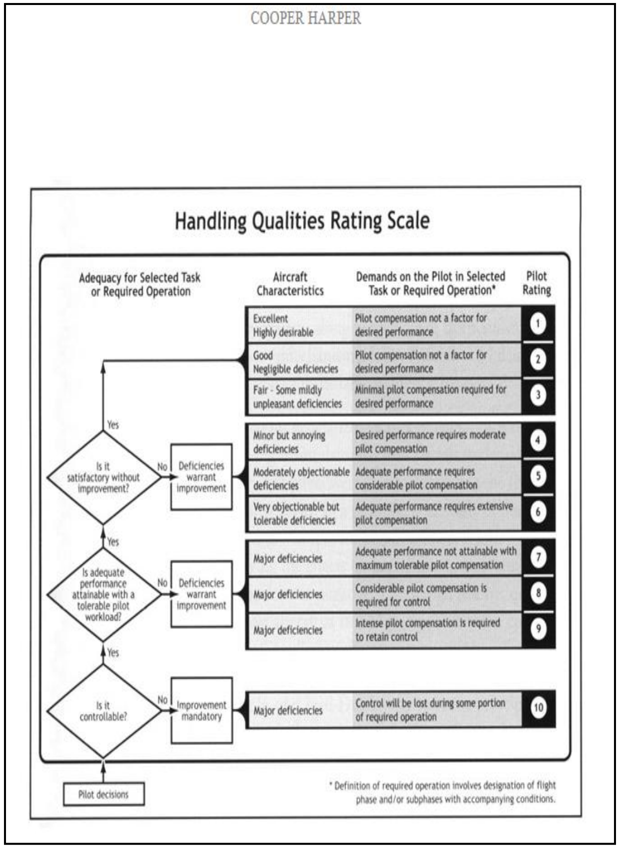
Sidestep

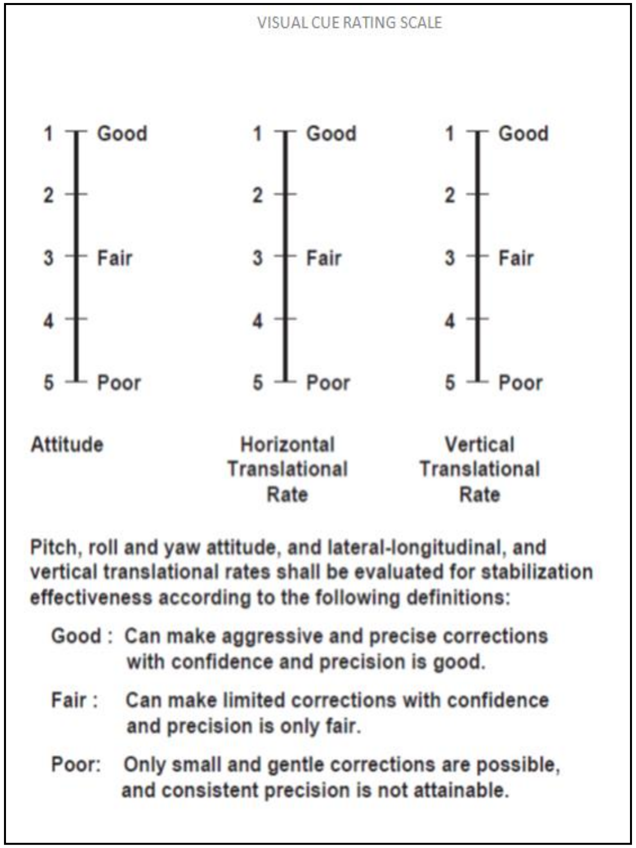
Heading +/- 5° (040°)
Altitude +/- 3 ' (30' AGL)
Position (including lateral) Accuracy pre and post stabilization (20 seconds)

1. **Approach and Landing.** This task began with the aircraft at 250 ft AGL moving at 80 KIAS toward the landing point, 1.5 nm away. Descent from 250 ft AGL began 0.8 nm from the hover point. The pilots were to approach the landing point in a straight line, and touchdown with 1.5 to 2 knots ground speed, minimal lateral drift and no hover. Metrics for this task include deviations from an ideal approach path, touchdown speed, touchdown heading, and touchdown location.
2. **Approach and Hover.** This task began with the aircraft at 250 ft AGL moving at 80 knots toward the landing point, 1.5 nm away. Descent from 250 ft AGL began 0.8 nm from the hover point. The pilots were to approach the hover point in a straight line and establish a 30 ft AGL hover.
3. **Hover.** Pilots maintained a 30 foot AGL hover for 2 minutes. Metrics for this task include deviations from an ideal position, heading, and altitude.
4. **Sidestep.** From a hover, the pilot relocated the aircraft using a sidestep maneuver, and returned to a stable hover above a pre-designated spot. Metrics include maximum lateral velocity, altitude maintenance, heading maintenance, relocation accuracy, 20 seconds pre and 20 seconds post hover quality (heading, altitude, and position).
5. **Crashes, loss of control, missed approaches, and/or aborted landings were reported separately.**

Qualitative Data Collection



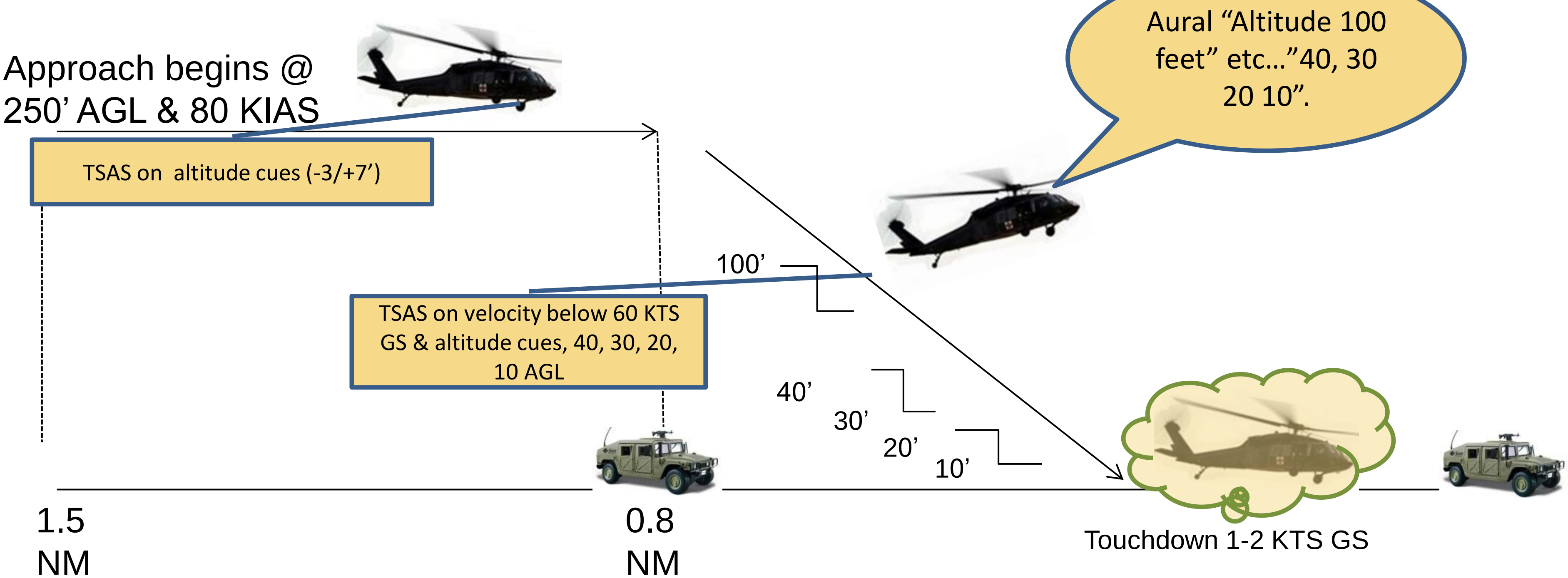


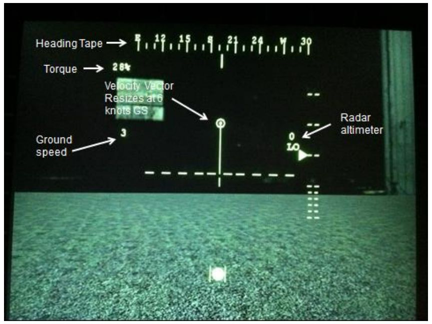


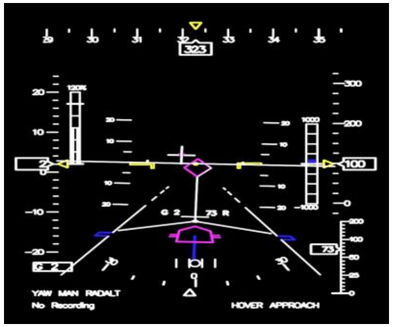
Summarized Results

- Detailed results are published in USAARL Report 2016-10 available on the USAARL website
- Flight performance data (i.e., flight path, speed, heading, altitude, position) were evaluated for Approach to Landing, Approach to Hover, Hover, and Sidestep Maneuvers
- Subjective assessments included results by maneuver for Cooper-Harper, Bedford Workload, and Visual Cue Index ratings
- Physiological Measures (biometrics) included heart rate, heart rate variability, respiratory rate, and galvanic skin response (findings will not be presented here)

APPROACH to LANDING Task Description







TSAS Parameters:

.75 kts to 5 kts = 1 HZ

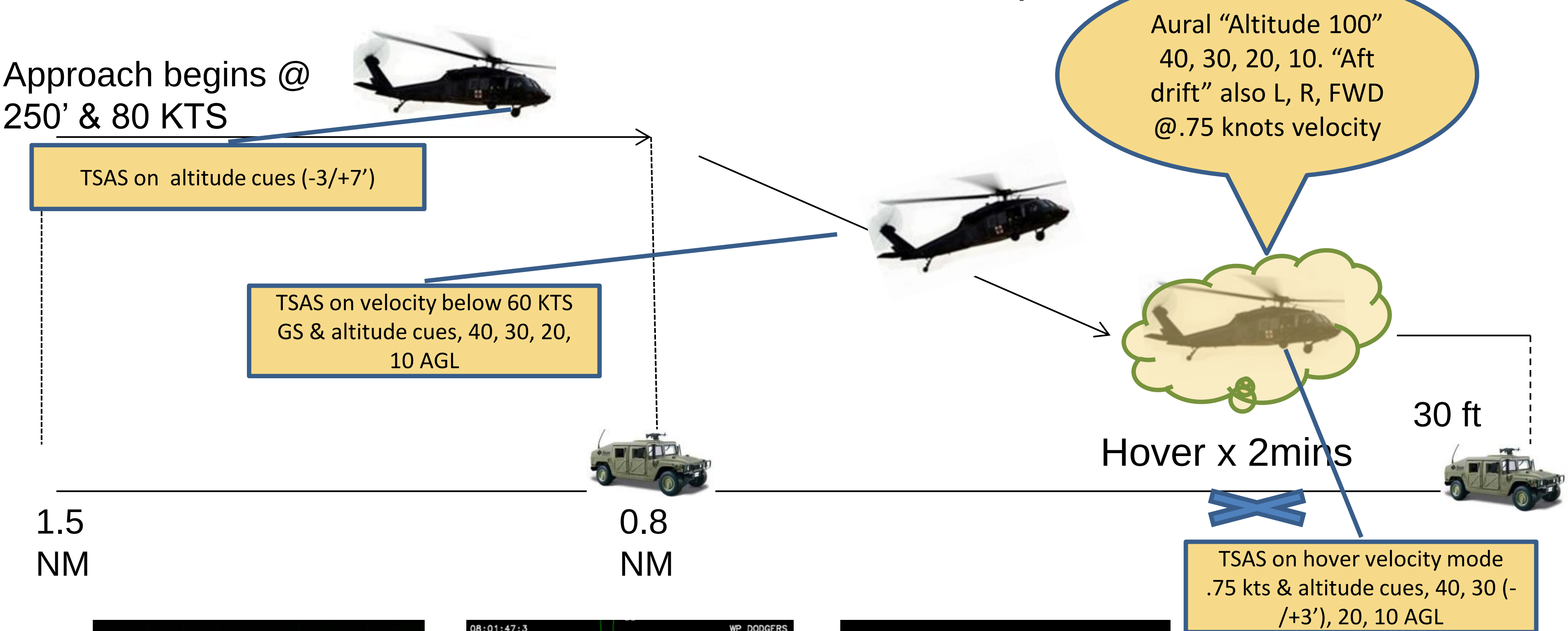
5 kts to 20 kts = 2 HZ

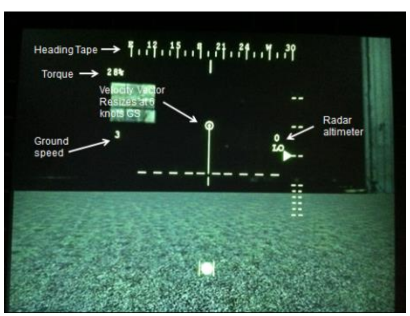
20 kts to 60 kts = 4 HZ

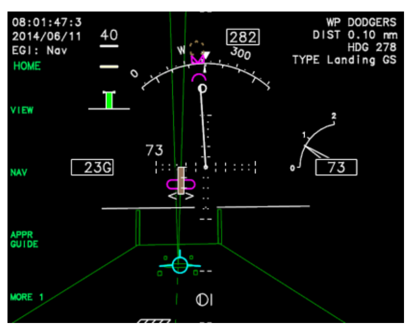
Approach to Landing Summarized Results

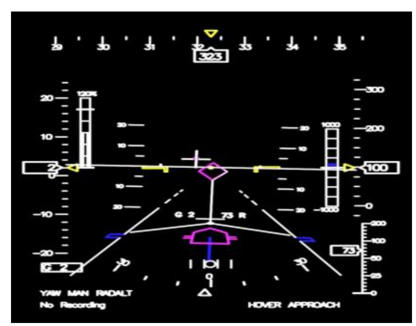
- BOSS significantly (sig) better than:
  - Legacy & FISH in position and speed maintenance
  - Legacy in heading maintenance
- FISH sig better than:
  - BOSS and Legacy in altitude maintenance
- Position maintenance sig better when BOSS was paired with TSAS or aural cueing than without (FLIR scene only)
- Subjective ratings: BOSS sig preferred over Legacy
- Workload perceived to be sig lower with BOSS than FISH or Legacy
- Workload significantly lower when visual symbology was paired with TSAS and aural cueing than with aural cueing alone.

APPROACH to Hover Task and Hover Task Description









TSAS Parameters:

.75 kts to 5 kts = 1 HZ

5 kts to 20kts = 2 HZ

20 kts to 60 kts = 4 HZ

Approach to Hover Summarized Results

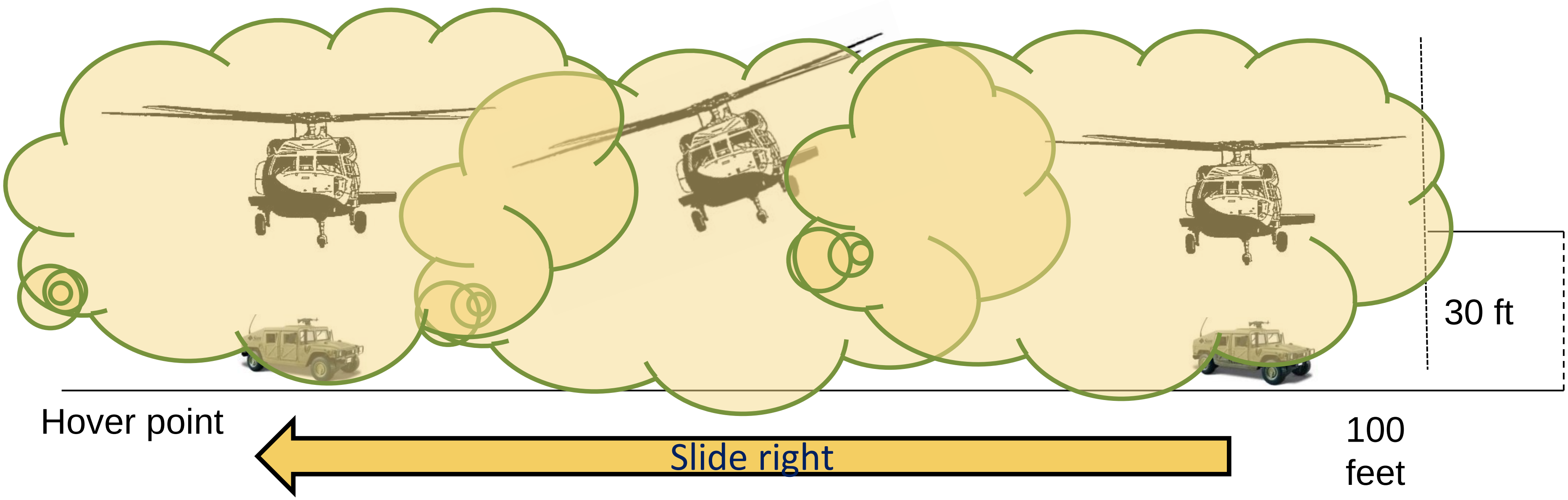
- BOSS sig better than:
  - Legacy & FISH in position maintenance
  - Legacy in altitude maintenance
- FISH sig better than:
  - Legacy in position, altitude, and speed maintenance
- BOSS resulted in best overall performance with supplemental TSAS and aural cues (the combination most preferred by test pilots)
- Subjective ratings: BOSS sig preferred over Legacy

Hover Summarized Results

- BOSS sig better than:
  - Legacy & FISH in position and altitude maintenance
- FISH sig better than:
  - Legacy in heading maintenance
- BOSS resulted in best overall performance with supplemental TSAS and aural cues (the combination most preferred by test pilots)
- Subjective ratings: BOSS sig preferred over Legacy

Sidestep Task

Task begin from a stabilized hover, “Ready mark”, pilot slides right 100’ and returns to a stabilized hover for 20 seconds.



Following
Hover x 2mins

Data: position, heading, airspeed, and altitude.

Sidestep Summarized Results

- Although begun and terminated at a hover, only the sidestep segment was analyzed
- BOSS and FISH sig better than Legacy
- BOSS with supplemental TSAS resulted in best performance (the display combination most preferred by test pilots)
- Subjective ratings:
  - Visual symbologies with TSAS easiest to fly, followed by TSAS and aural cues
  - Visual symbologies with aural cues was ranked most difficult

Study 1 General Conclusions

1. Test pilots performed better using advanced visual symbologies (BOSS and/or FISH) when combined with a supplemental form of cueing (aural and/or tactile).
2. Advanced visual symbologies outperformed Legacy symbology for almost all maneuvers.
3. Test pilots' preferred supplemental cueing modality was dependent on the type of visual symbology and/or flight maneuver.
4. As configured in this study, aural cueing degraded flight performance in some test pilots when using either Legacy or FISH visual symbology sets due to pilot-induced oscillation during the hover and sidestep maneuvers.

Study 1 General Conclusions

5. Overall, subjective and flight performance measures indicated that the BOSS symbology was the preferred visual symbology set.
6. Pilots preferred aural cues that provided situational information over aural cues that demanded corrective action to satisfy a required performance measure.
7. In general, test pilots preferred the TSAS cueing display over the aural cueing display.

USAARL STUDY 2: INTEGRATED CUEING ENVIRONMENT TESTING: PILOT CUEING SYNERGIES FOR DEGRADED VISUAL ENVIRONMENTS

- Goal of the study was to evaluate the Integrated Cueing Environment (ICE) visual symbology which overlaid imagery from a FLIR sensor and assess the synergistic effects of aural and tactile cues.
- Assess the effect of each configuration on flight performance, pilot workload, and situational awareness.
- Assess the relative efficacy of the ICE cueing package when teamed with Panel-Mounted Display (PMD) and/or Head-Mounted Display (HMD).
- Make recommendations for managing the integration of the ICE cueing package technologies into helicopter operations.

Study Objectives

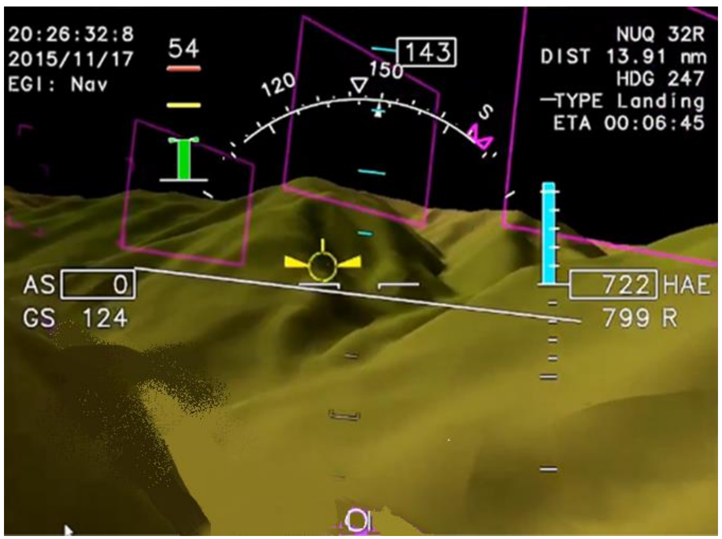
- Conduct DVE simulator flight tests of the selected tasks under 12 combinations of the two types of display, the aural and tactile cueing sets, and a distractor task (the Modified Multi-Attribute Task Battery or MATB II set to high workload setting)
- Evaluate the ICE display and cueing set combinations using flight performance metrics, subjective ratings, and psychophysiological metrics

ICE Visual Display

PMD - UH-60M instrument panel emulation

HMD - SA Photonics Low Cost Augmented Reality system (LARS)

ICE Visual Symbology



Enroute

Hover/Approach/Takeoff

Tactile Cues

- TSAS provided intuitive non-visual information to the pilot via their sense of touch
  - Altitude
  - Ground speed
  - Drift
  - Velocity vector

Aural Cues

Advisory Messages

- “Speed Guidance On”
- “Start decent”

Caution Messages

- “Vertical speed excessive” (vertical speed > 540 fpm and within 5 seconds of contact)
- “Torque” (Torque greater than 100%)

Warning Messages

- “Pull up! Pull up!” (vertical speed > 540 fpm and within 5 seconds of contact)
- “Over torque” (Torque greater than >120%)

Study Plan

- During simulated night flight, the imagery was displayed on a UH-60M PMD or on a SA Photonics high definition (HD), wide FOV, binocular HMD
- During simulated day flight, composite imagery was displayed on both the PMD and HMD
- Additionally, the synergistic effects of aural and tactile cues were assessed
- All conditions were tested with and without a distraction task
- Seven experienced test pilots, selected by the sponsor, performed the flight tasks

Study Plan (cont.)

- ICE symbology test configurations were evaluated three ways:
  1. flight performance metrics that track deviations from an ideal flight path
  2. workload metrics
  3. pilot subjective assessments
- Subjective measures on workload and stress:
  1. Cooper-Harper Handling Qualities Ratings Scale
  2. National Aeronautics and Space Administration Task load Index (NASA-TLX) workload assessment
  3. Situational Awareness Rating Technique (SART) data
  4. Free reports from each pilot

Configurations

	Night DVE Sensor + Symbology on Selected Display		Day DVE Sensor on PMD Symbology on Both
	PMD	**HMD**	**PMD & HMD**
Aural & Tactile Cueing Off MATB II On	1	2	9
Aural & Tactile Cueing Off MATB II Off	3	4	10
Aural & Tactile Cueing On MATB II On	5	6	11
Aural & Tactile Cueing On MATB II Off	7	8	12

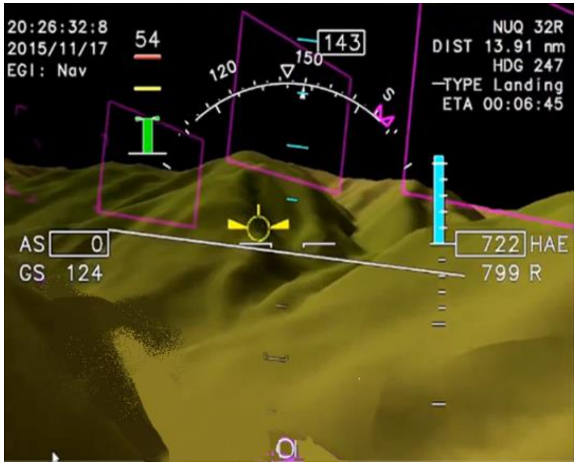
- Test using Pseudorandomized Order
- Time Required
  - 18 hours per pilot
  - 7 pilots
  - 126 total hours

Flight Tasks

Enroute Task Description

Aural:
"Check altitude"

Aircraft @ 250' AGL
80 KIAS

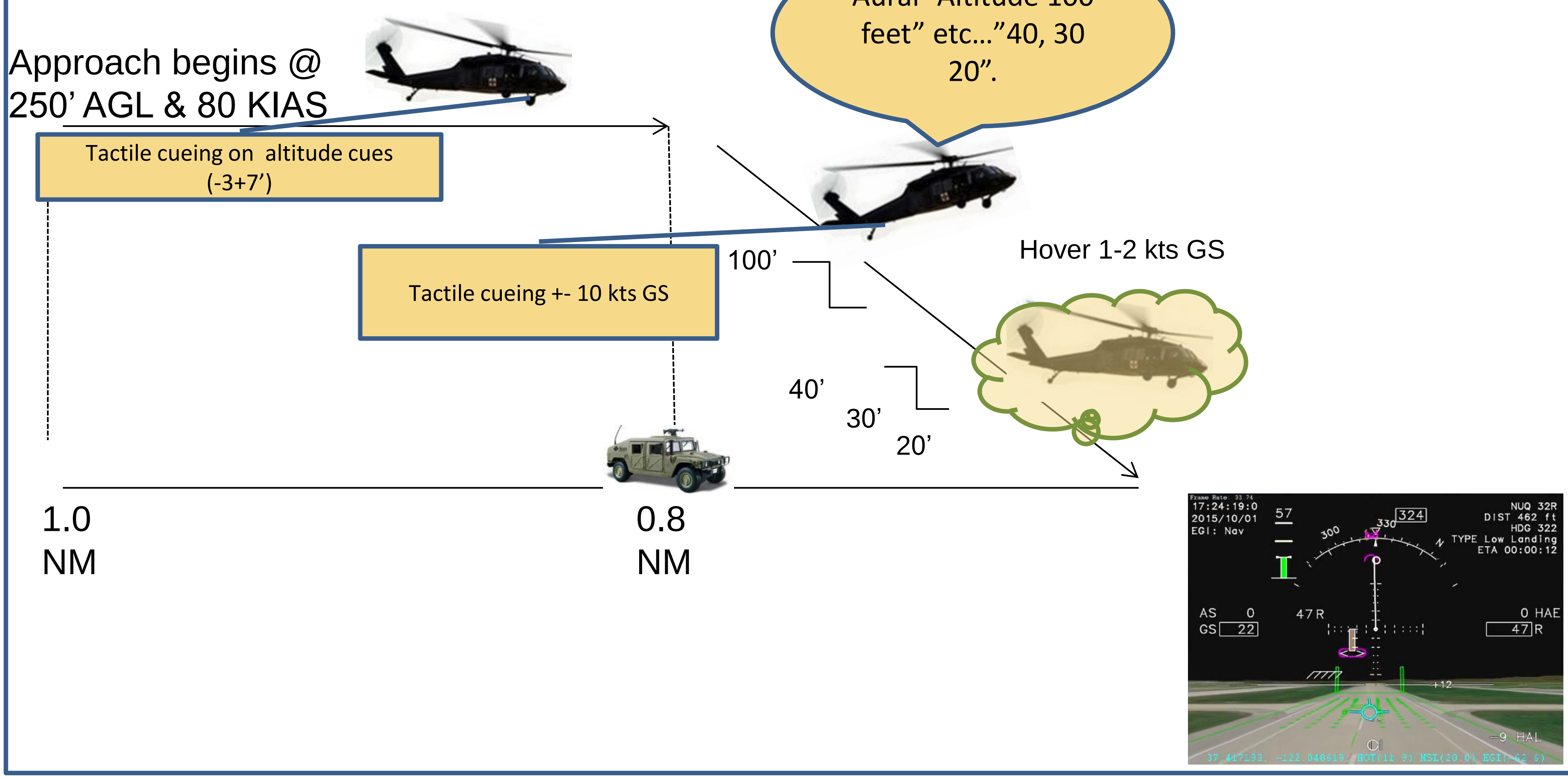


Tactile cueing on altitude cues
(Outside Pathway box)
Heading cues(+/- 5°)

Tactile cueing on velocity cues
(+/- 10 KIAS)

Flight Tasks

Approach to Hover Task Description



Flight Tasks

Hover Task Description

Aural “Altitude 40’, 30’, 20’, 10. “Aft drift”

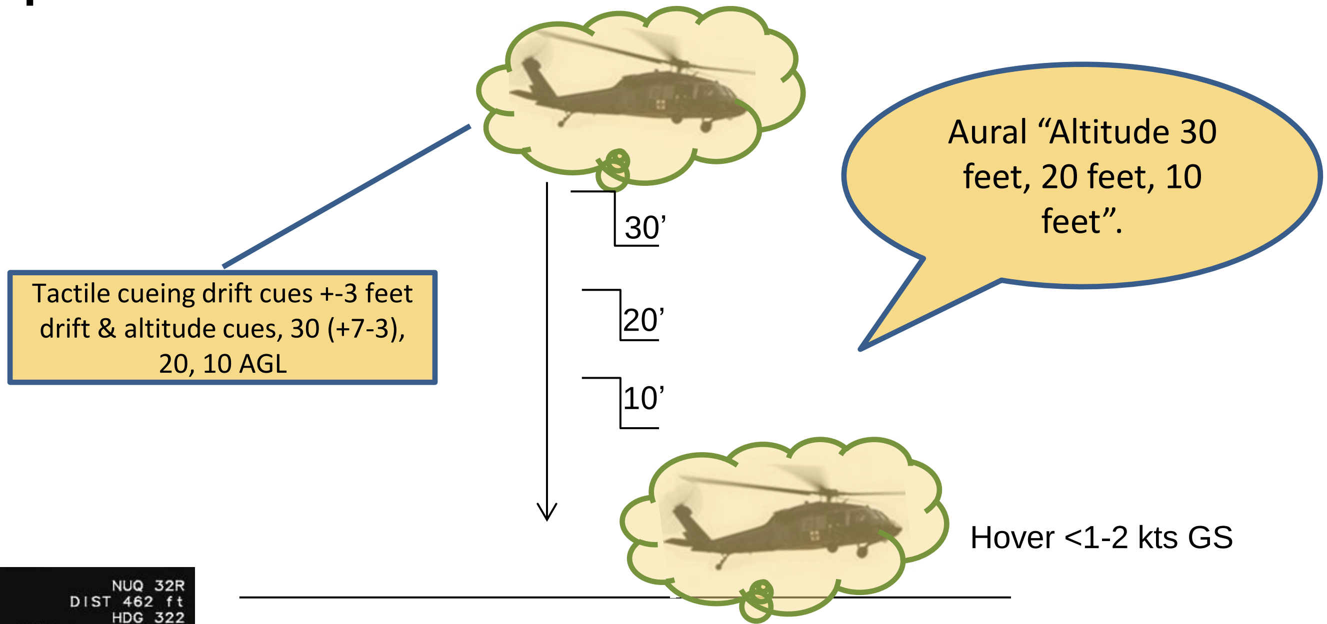
30 ft

Hover x 1 min

Tactile cueing on hover altitude cues 30’ (+-3’) AGL

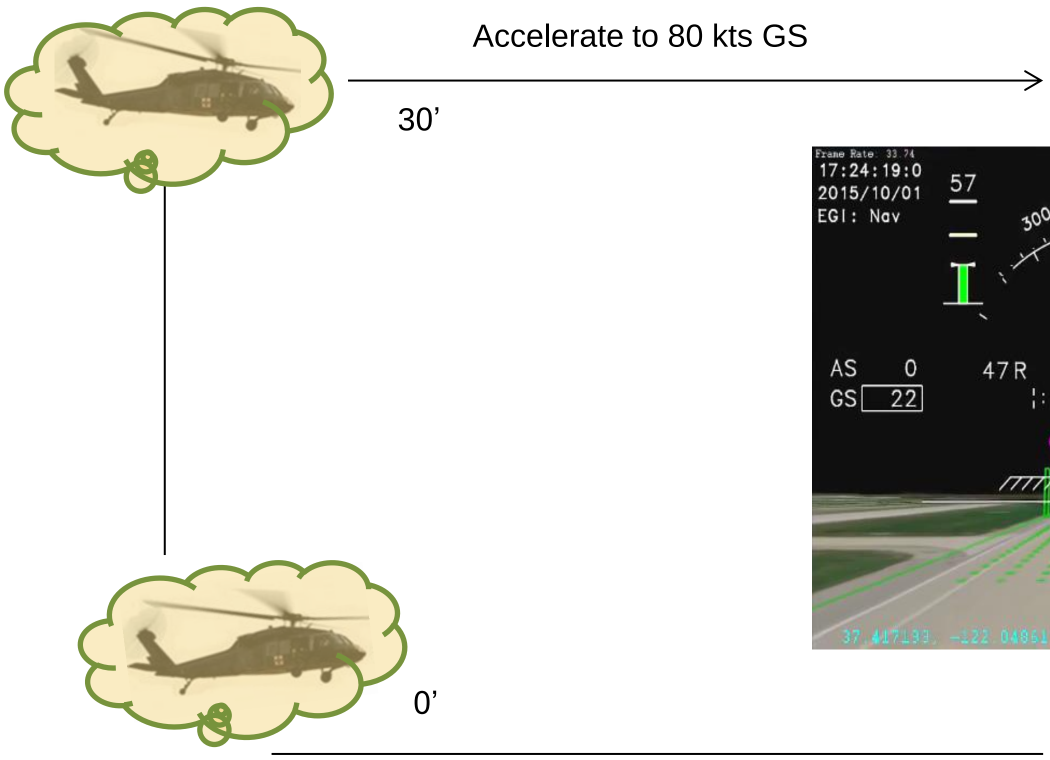
Flight Tasks

Landing Task Description



Flight Tasks

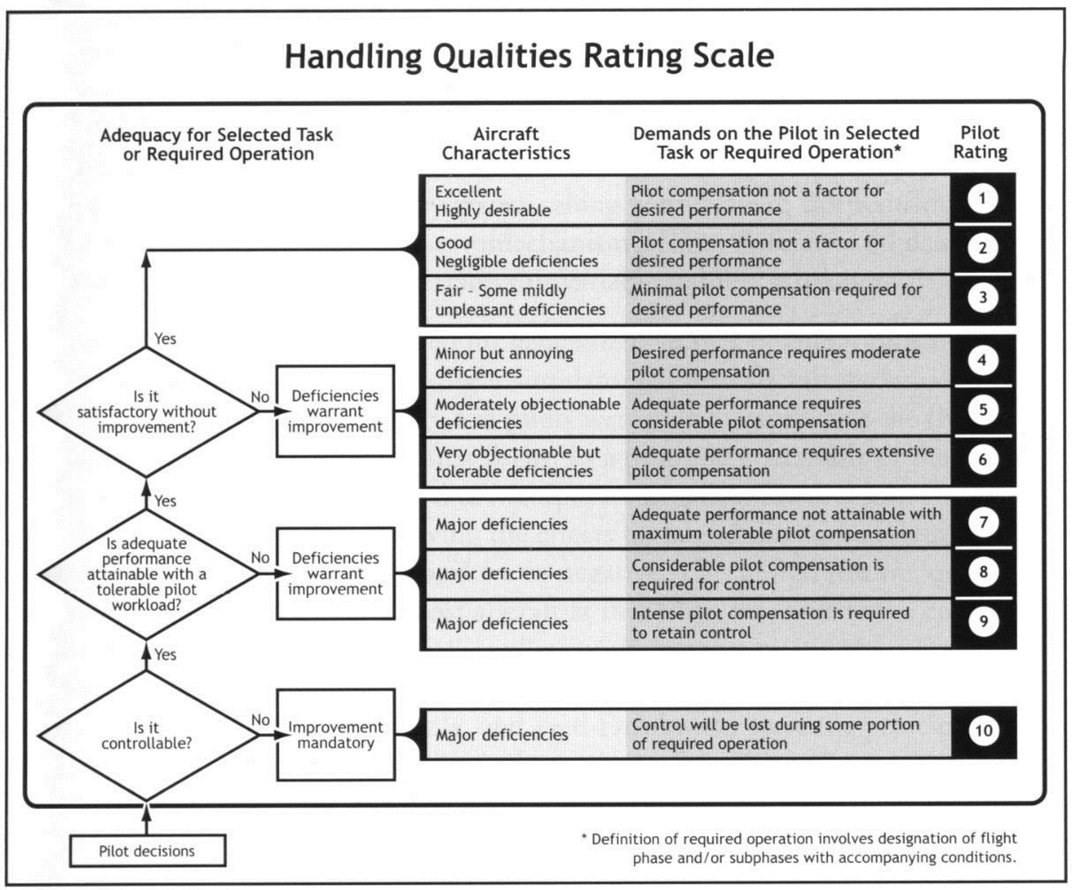
Takeoff Task Description



Objective Flight Performance Measures

- **Enroute**
  - Metrics: Deviations from an ideal flight path altitude, speed, and position
  - Standards: Heading +/- 5° Altitude within center of Pathway Box Airspeed +/- 5 KIAS desired +/-10 KIAS Adequate
- **Approach to Hover**
  - Metrics: Deviations from an ideal approach path and heading
  - Standards: Heading +/- 5° Altitude +7/-3 ‘ Airspeed on cues Ground track alignment (minimal drift)
- **Hover**
  - Metrics: Drift, altitude, and heading deviations
  - Standards: Heading +/- 5° Altitude +/- 3 ‘ Drift +/- 3 ‘
- **Landing**
  - Metrics: Maximum velocity, heading and position when aircraft touched down
  - Standards: Heading +/- 5° < 2 KTS Ground Speed Touchdown Position +/- 3 ‘
- **Takeoff**
  - Metrics: Heading and position deviations
  - Standards: Heading +/- 5° Drift +/- 3 ‘

Subjective Metrics



NASA Task Load Index										
Mental Demand - How mentally demanding was the task?										
0 Low	1	2	3	4	5	6	7	8	9	10 High
Physical Demand - How physically demanding was the task?										
0 Low	1	2	3	4	5	6	7	8	9	10 High
Temporal Demand - How hurried or rushed was the pace of the task?										
0 Low	1	2	3	4	5	6	7	8	9	10 High
Performance - How successful were you in accomplishing what you were asked to do?										
0 Perfect	1	2	3	4	5	6	7	8	9	10 Failure
Effort - How hard did you have to work to accomplish your level of performance?										
0 Low	1	2	3	4	5	6	7	8	9	10 High
Frustration - How insecure, discouraged, irritated, stressed, and annoyed were you?										
0 Low	1	2	3	4	5	6	7	8	9	10 High

Subjective Metrics

Situational Awareness Rating Technique										
Demands on Attentional Resources - Instability, complexity, variability of situation										
0 Low	1	2	3	4	5	6	7	8	9	10 High
Supply of Attentional Resources - Alertness, spare mental capacity, concentration of attention, division of attention										
0 Low	1	2	3	4	5	6	7	8	9	10 High
Understanding of the Situation - Information quantity, information quality, familiarity with situation										
0 Low	1	2	3	4	5	6	7	8	9	10 High

Physiological Measures

- Heart Rate
- Heart Rate Variability
- Respiratory Rate
- Electroencephalogram (EEG)

Summarized Results

- Detailed results are published in USAARL Report 2017-04 (limited distribution)
- Flight performance data were analyzed for Enroute, Approach to Hover, Hover, Landing, and Takeoff
- Subjective assessments included results by maneuver for Cooper-Harper Handling Qualities Ratings Scale, NASA-TLX workload assessment, SART, and free reports from each pilot
- Physiological measures included heart rate, heart rate variability, respiratory rate, and EEG (findings will not be presented here)

Night DVE Flights Summary

- Pilots considered symbology very effective on the HMD and PMD
- Imagery, aural cueing, and tactile cueing were all rated as effective
- Enroute Phase
  - Pilots better able to maintain an ideal flight path with the PMD than with the HMD
  - No sig difference in handling quality ratings for the two displays
  - No sig difference in handling quality ratings for cues on vs cues off
- Approach to Hover/Hover/Landing/Takeoff Phases
  - No observed differences in flight performance
  - No observed differences in handling quality ratings
- NASA TLX Scores/SART Score
  - No difference when using HMD vs using PMD
  - No difference for cues on vs cues off

Day DVE Flights Summary

- PMD symbology was given a better effectiveness rating
- Imagery, aural cueing, and tactile cueing were all rated as effective
- No differences in flight performance during any phase of flight
- No differences in handling quality ratings during any phase of flight
- No differences in NASA TLX Scores for cues on vs cues off
- No differences in SART Scores for cues on vs cues off

Study 2 General Conclusions

- PMD vs HMD
  - Pilots better able to maintain an ideal flight path with the PMD during enroute phase (difference in flight performance not operationally significant)
  - No difference in flight performance during any other phase of flight
  - PMD symbology rated very effective and HMD symbology rated effective
  - No difference in HQR, NASA TLX, SART, or psychophysiological measures
- Cueing
  - Pilots considered aural and tactile cueing effective
  - No difference in flight performance, HQR, NASA TLX, SART, or psychophysiological measures
- Overall performance very good in all phases of flight

Future ICE Research

- Plans are underway to conduct the next phase of testing in the next few months in which line pilots who have not been previously exposed to the ICE cueing system will be used as research participants.
- The overall testing objectives will be the same as the previous study, such that the symbology will be assessed on both a PMD and HMD, and the synergistic effects of aural and tactile cues will be examined.

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