How DVE Predisposes Rotary Wing Pilots to SD & Specific Countermeasures for Critical Phases of Flight

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Spatial Orientation

- Ability to perceive our position, motion and attitude within a fixed frame of reference in 3-dimensional space
- It is essential for our survival

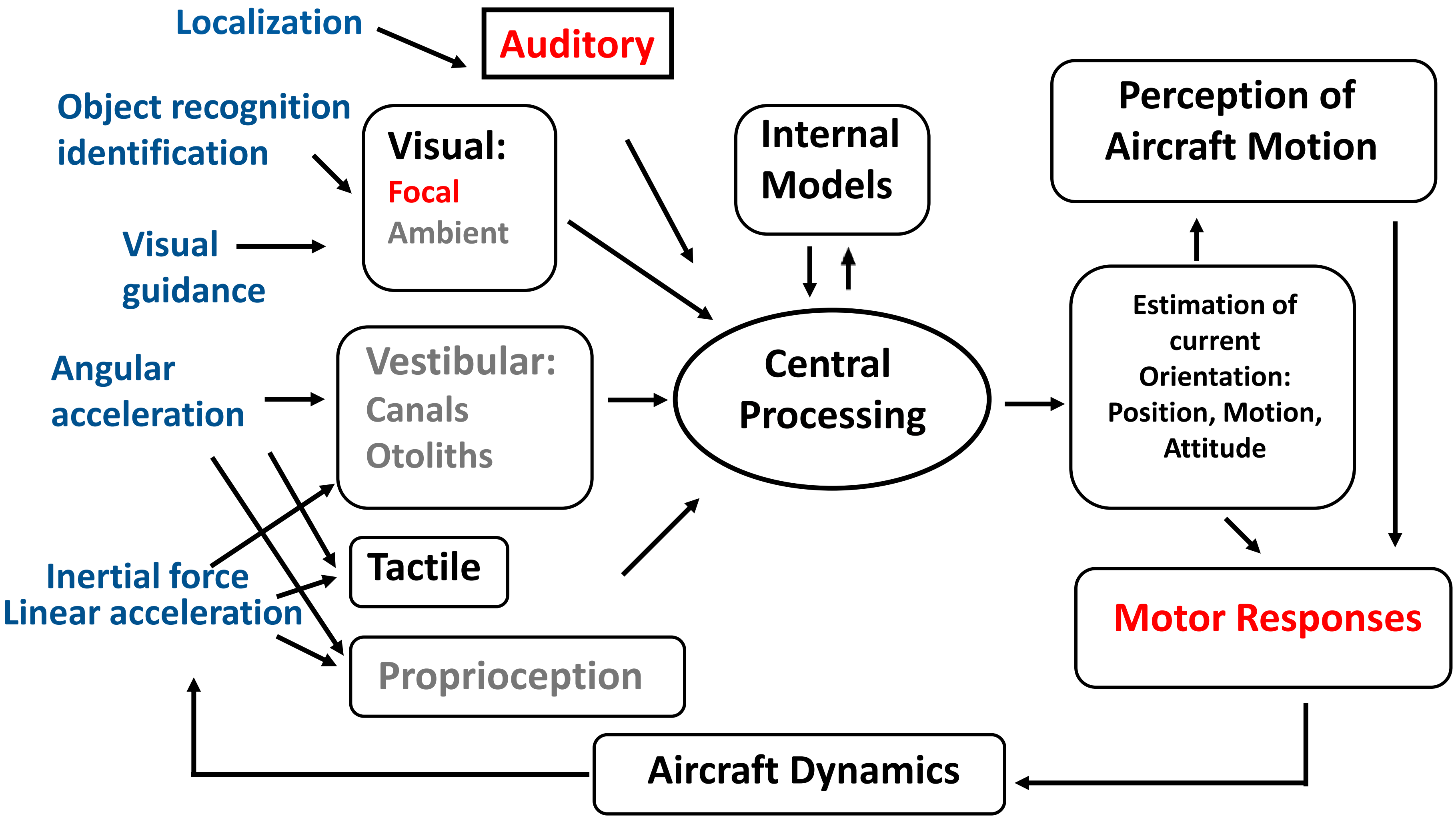
Spatial Orientation is not identical to Postural Stability

- Postural stability is the ability to maintain the body centre of mass within specific limits

ASIC/ASCC AIR STD 61/117/1

Spatial Disorientation (SD) is …

- .... a term used to describe a variety of incidents occurring in flight where the aviator fails to sense correctly the position, motion or attitude of the aircraft or of him or herself within the fixed co-ordinate system provided by the surface of the earth and the gravitational vertical
- In addition, errors in perception by the aviator of his or her position, motion or attitude with respect to his or her aircraft, or of his or her own aircraft relative to other aircraft, may also be embraced within a broader definition of spatial disorientation in flight
- A normal physiological response to an abnormal environment
- SD is not equivalent to postural instability

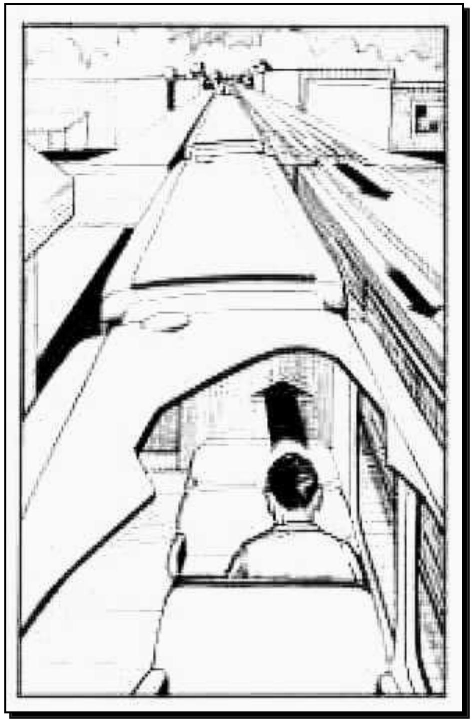


From: Cheung, B. (2004) Spatial Orientation – Nonvisual Spatial Orientation Mechanisms. In: F. Previc, W. Ercoline (Eds.) Spatial Disorientation in Aviation. Progress in Astronautics and Aeronautics Volume 203. pp 37-94. American Institute of Aeronautics and Astronautics, Inc. Restoin, Virginia

Degraded Visual Environment (DVE) includes low visibility in:

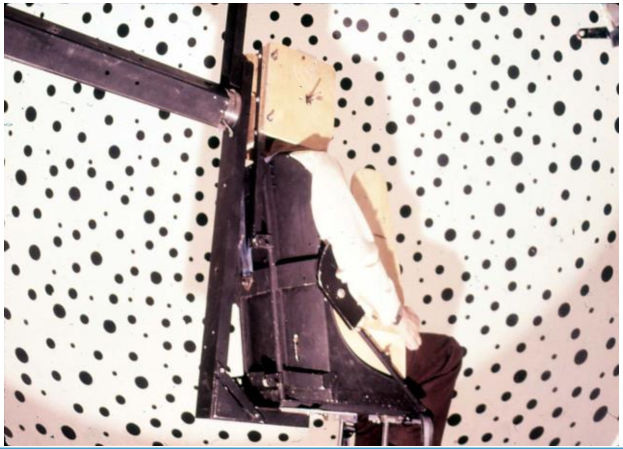
- Poor weather conditions (snow/sand/dust/fog/smog)
- Flying at night without NVG
- NVG flight on low illumination nights (<1.5 mLux) in "good" weather conditions

Misleading cues can be more dangerous than the absence of cue – visually induced sensation of motion (vection)



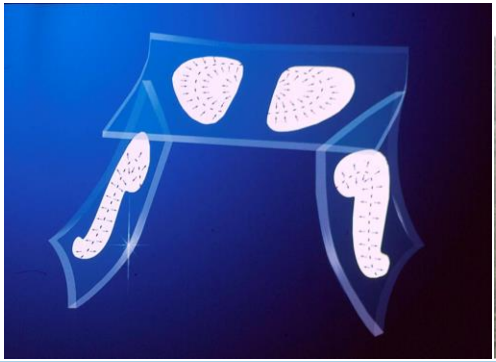
Circularvection and linearvection (Howard & Cheung 1989)

- Requires large retinal area (including periphery)
- More dependent on background visual field
- Relies on moving textures (sluggish response, low frequency)
- Can occur with optically degraded stimuli



Limitations of the otolith organs

- Inherent inability to distinguish between gravity & linear acceleration
- Otolith organs are only accurate for determining the direction of the vertical with the head upright pitched forward 25° .
- Limited threshold (Y and X = 0.005-0.01G; Z = 0.01-0.1G)
- Higher threshold & greater error in detecting vertical motion (Malcolm & Melville-Jones 1974)



DVE Precipitates SD

- Loss of external visual reference
- Lack of correct feedback for lateral, longitudinal and vertical drift
- Inherent perceptual delay in re-acquiring orientation information from VMC to IMC.
  - Further perceptual delay while disoriented (Cheung et al. 2003, 2004)
- Intolerance for error & corrections when close to the ground
- Most instrument display was developed for cruise flight only

Problem Space	Solution Space	Deductions
DVE	1. Improved Handling Qualities (DAFCS, FBW)	Intermediate-term & platform specific
	2. Sensors	Intermediate-term & complex
	3. Symbology	Near-term & ready

Enabler for all

4. Improved understanding and characterization of particulates in order to provide physical and chemical abatement or flight procedure (long-term)
5. pilot ground based and in-flight training in handling DVE conditions

NIAG (July 2013) – " … no single sensor technology can provide the capability to 'see through' DVE and provide high resolution vision over the wide range of requirements for safe helicopter operations in various operational modes." Some level of fusion is necessary.

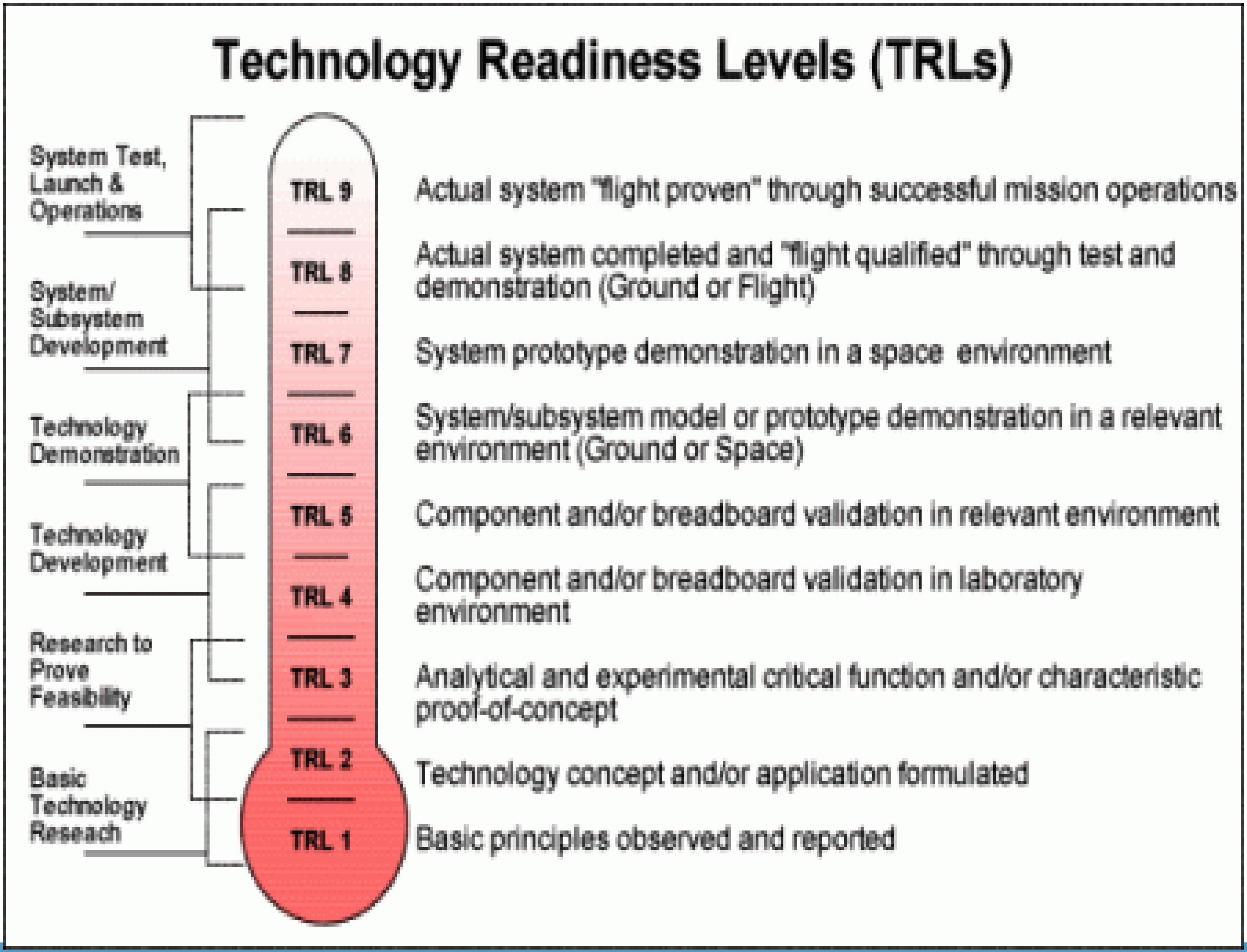
- In 2011, the NATO RTO HFM TG 162 on Rotary-Wing Brownout Mitigation suggested:
  - implementation of DVE symbology might yield an 80% reduction in risk during departure and approach in DVE conditions
  - Specifically, DVE symbology must address the physiological and perceptual limits

- Effective cueing in DVE requires:
  - Intuitiveness (minimal cognitive processing)
  - Minimal latency
  - Increases in overall SA without increase in workload
  - Natural visual guiding attributes
  - Division of attention without attention capture

  - Helmet mounted HUD
    - Reduction of head down time
    - Elimination of the need to change accommodation/re-focus
    - Continuous knowledge of real and virtual information in the far domain

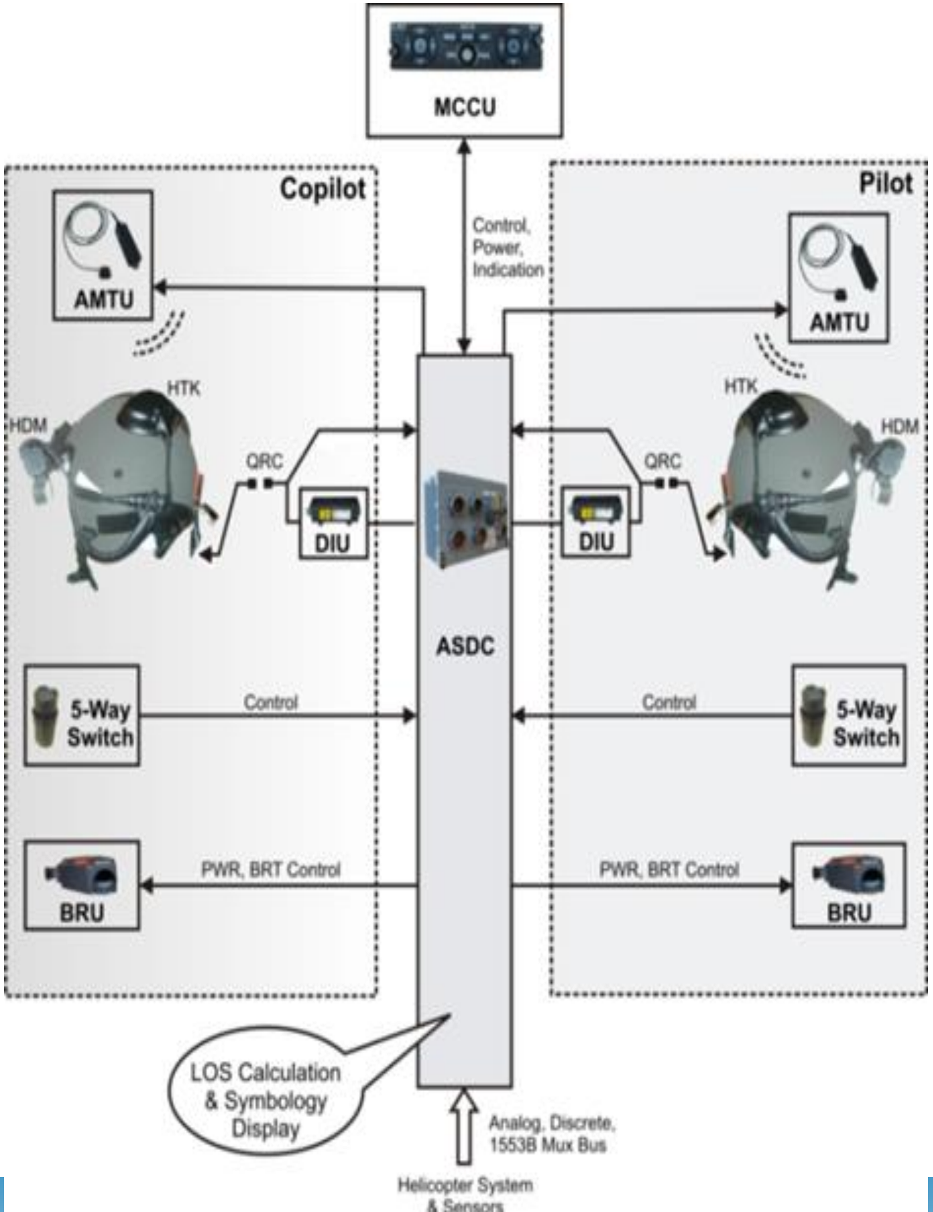
Symbology system concepts that have reached maturity at TRL 6-7

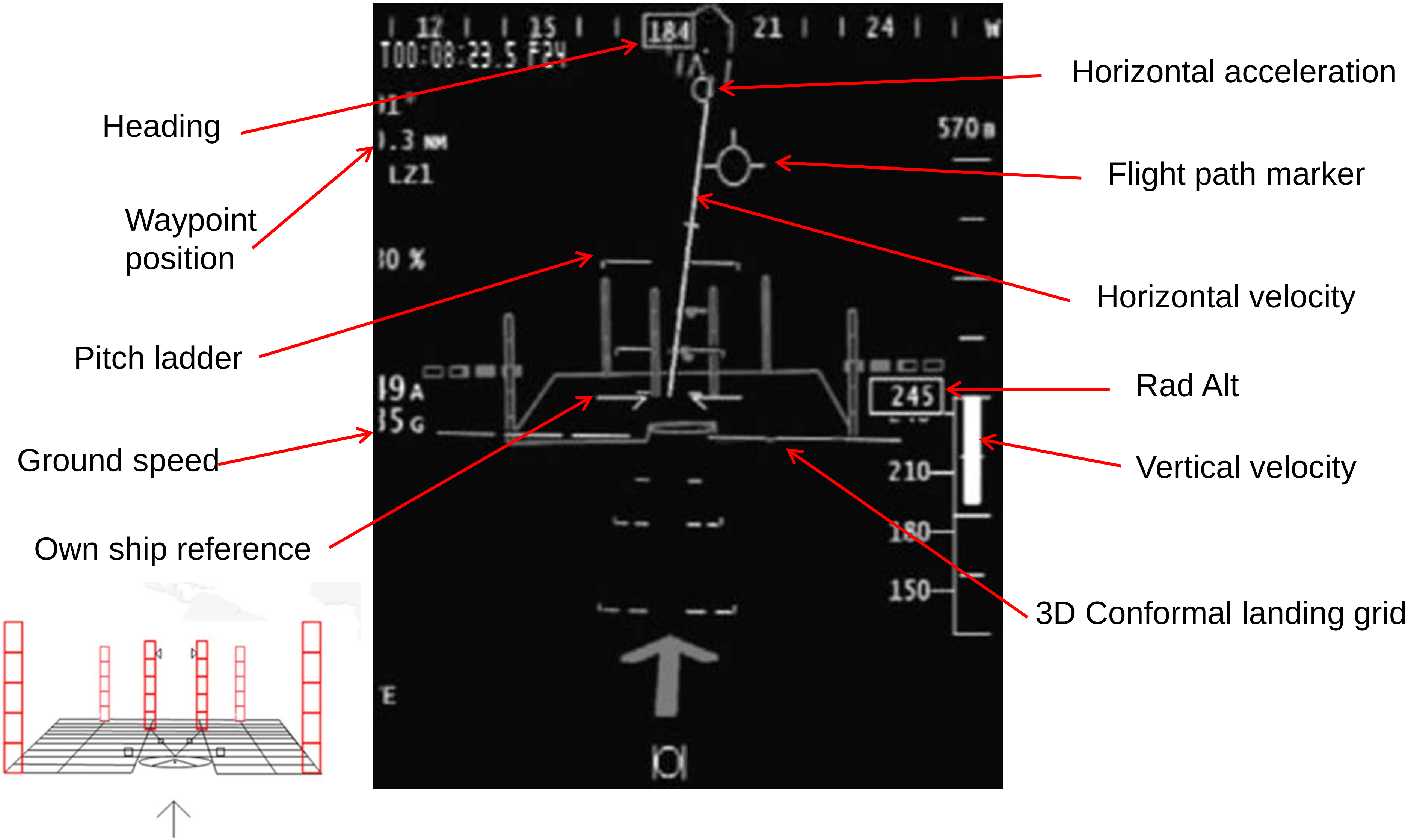
- Conformal system (HDTS-DVE. Elbit System Ltd)
- 2D system with improved scaling (BOSS, ARMDEC, US Army)



HGU-56P

Day Display Module



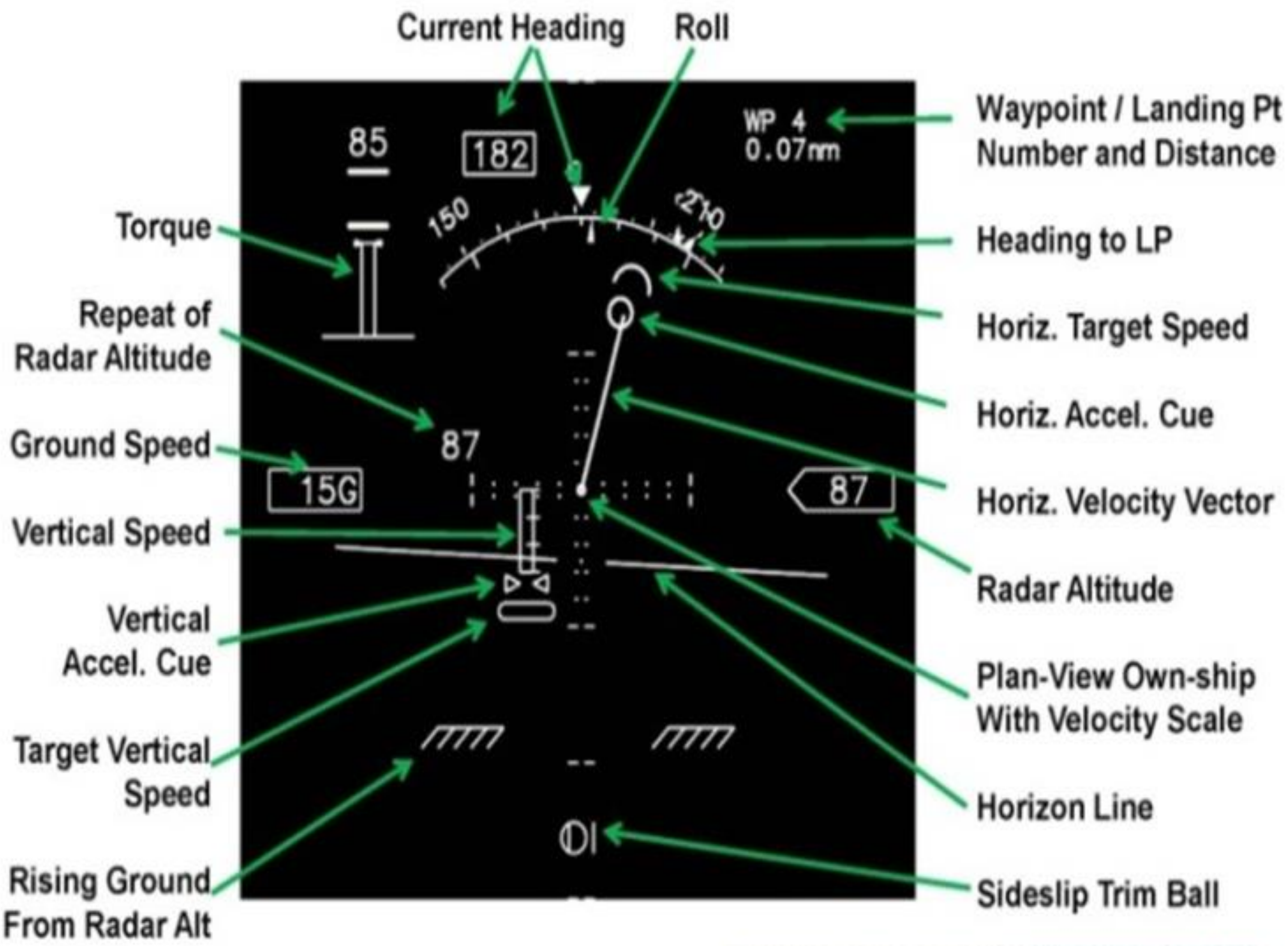

Heading
Waypoint position
Pitch ladder
Ground speed
Own ship reference
Horizontal acceleration
Flight path marker
Horizontal velocity
Rad Alt
Vertical velocity
3D Conformal landing grid
12
15
184
21
24
570
LZ1
245
210
180
150

UNCLASSIFIED

U.S. ARMY RDECOM

HAT Page Symbols

AMRDEC



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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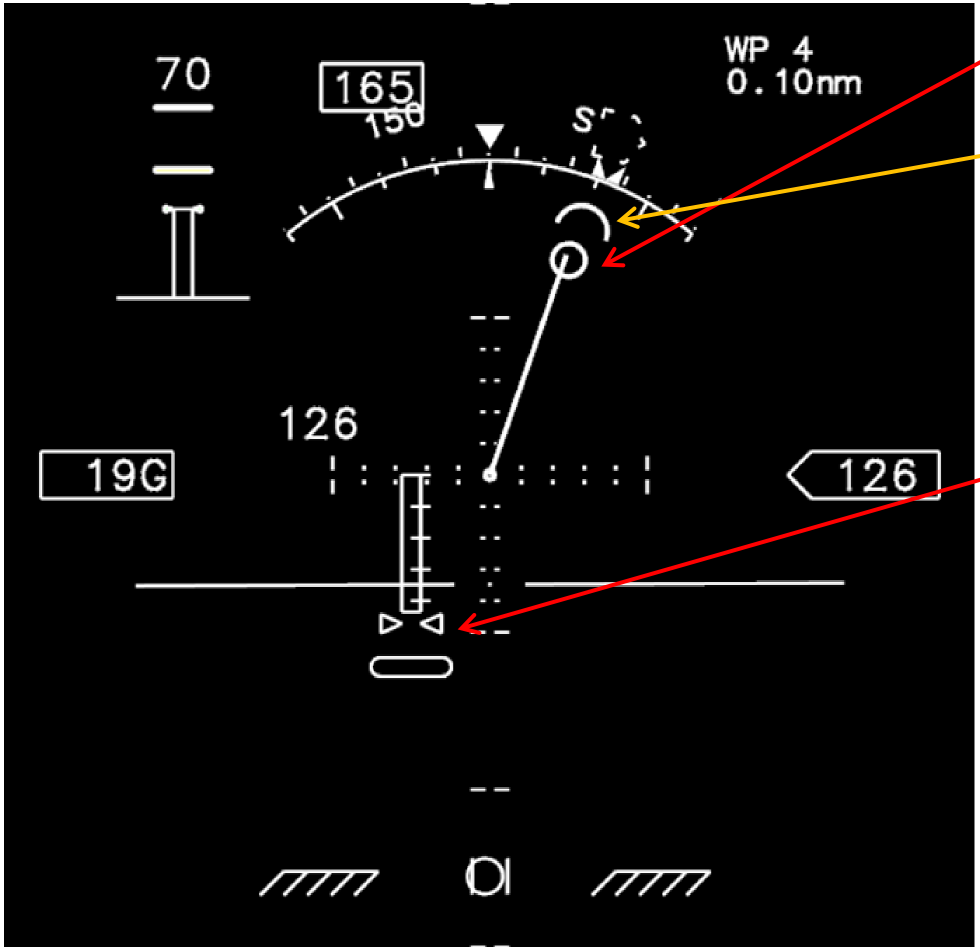
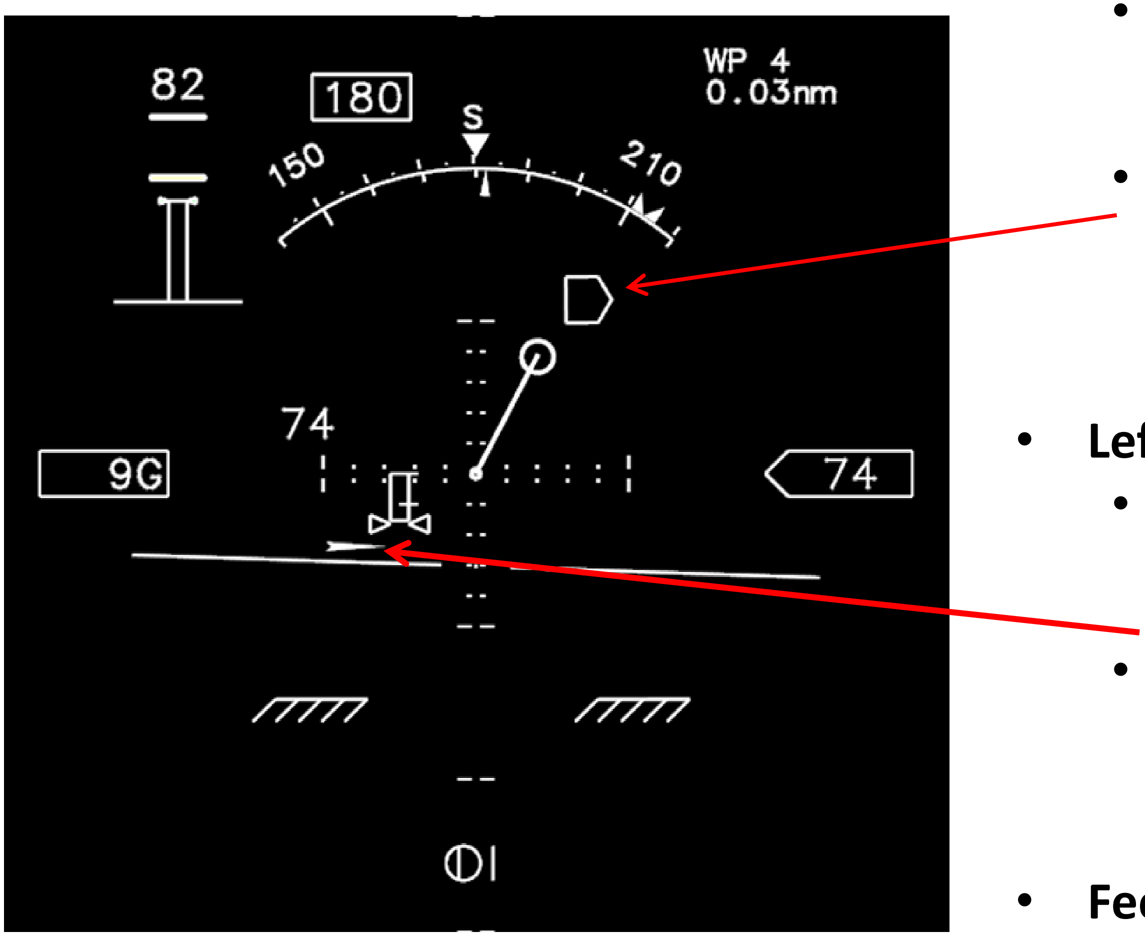
BOSS Strategy During Approach



- **Right Hand (Cyclic)**
  - Control the horizontal acceleration cue "ball" symbol directly
  - Place the "ball" in the target speed "cup" and track it
- **Left Hand (Collective)**
  - Control the vertical acceleration cue "bow tie" symbol directly
  - Place the "bow tie" in the target vertical speed oval and track it
- **Feet (Pedals)**
  - At low speeds, put a pedal input to swing the velocity vector and target speed "cup" to the centerline if needed

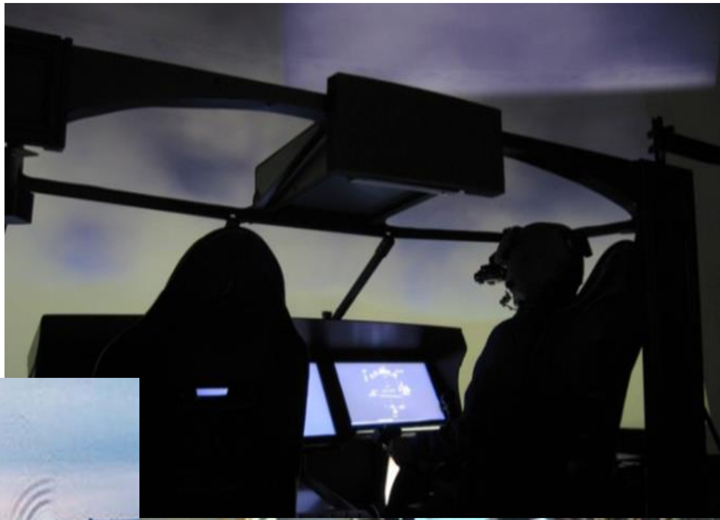
BOSS – Strategy During Hover



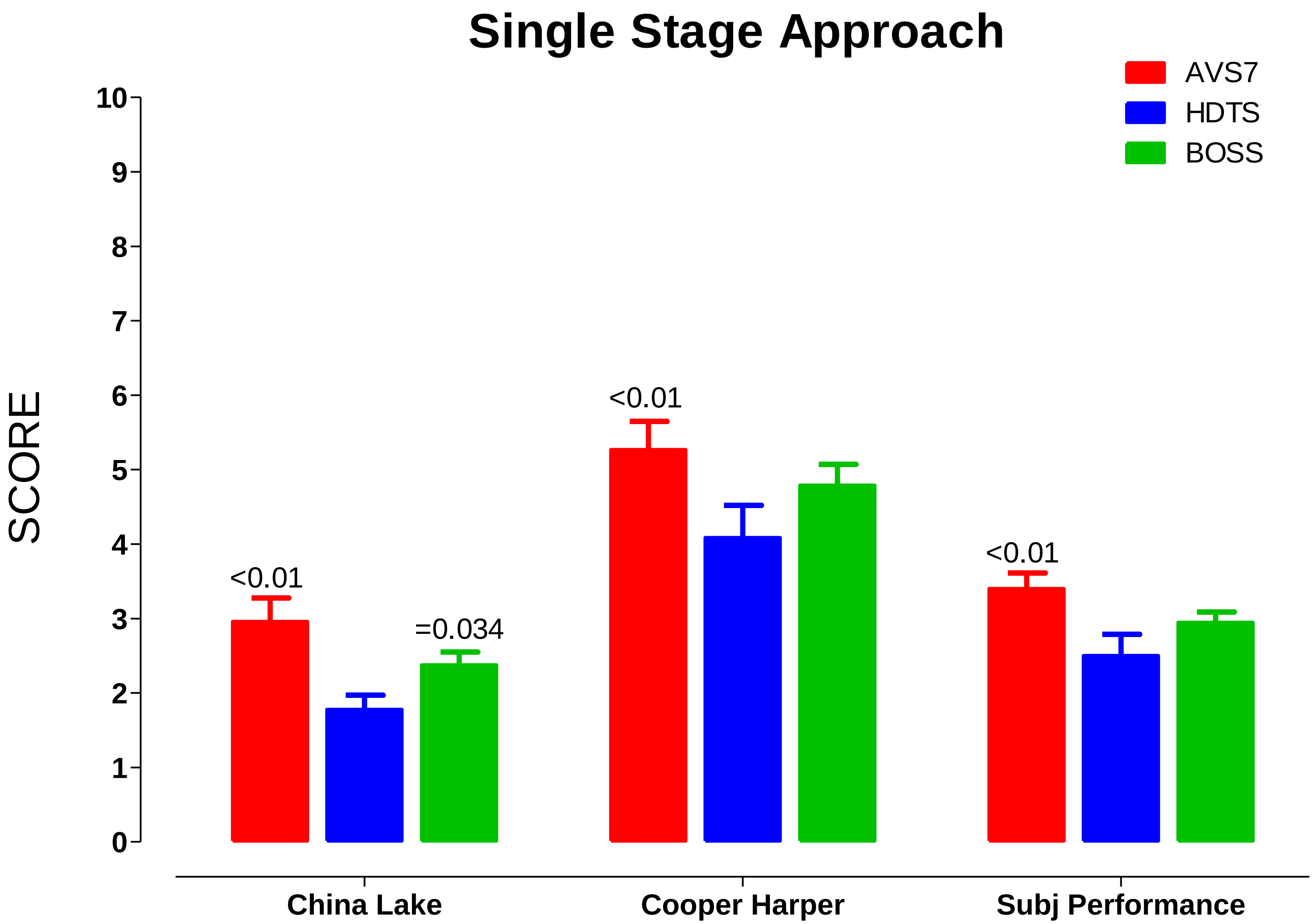
- **Right Hand (Cyclic)**
  - Control the horizontal acceleration cue "ball" symbol directly
  - Place the "ball" symbol in target hover symbol "doghouse" and track it
- **Left Hand (Collective)**
  - Control the vertical acceleration cue "bow tie" symbol directly
  - Place the "bowtie" symbol on the target altitude "bug" and track it
- **Feet (Pedals)**
  - Use pedal inputs to change heading while maintaining position and altitude

Simulator and in-flight investigation

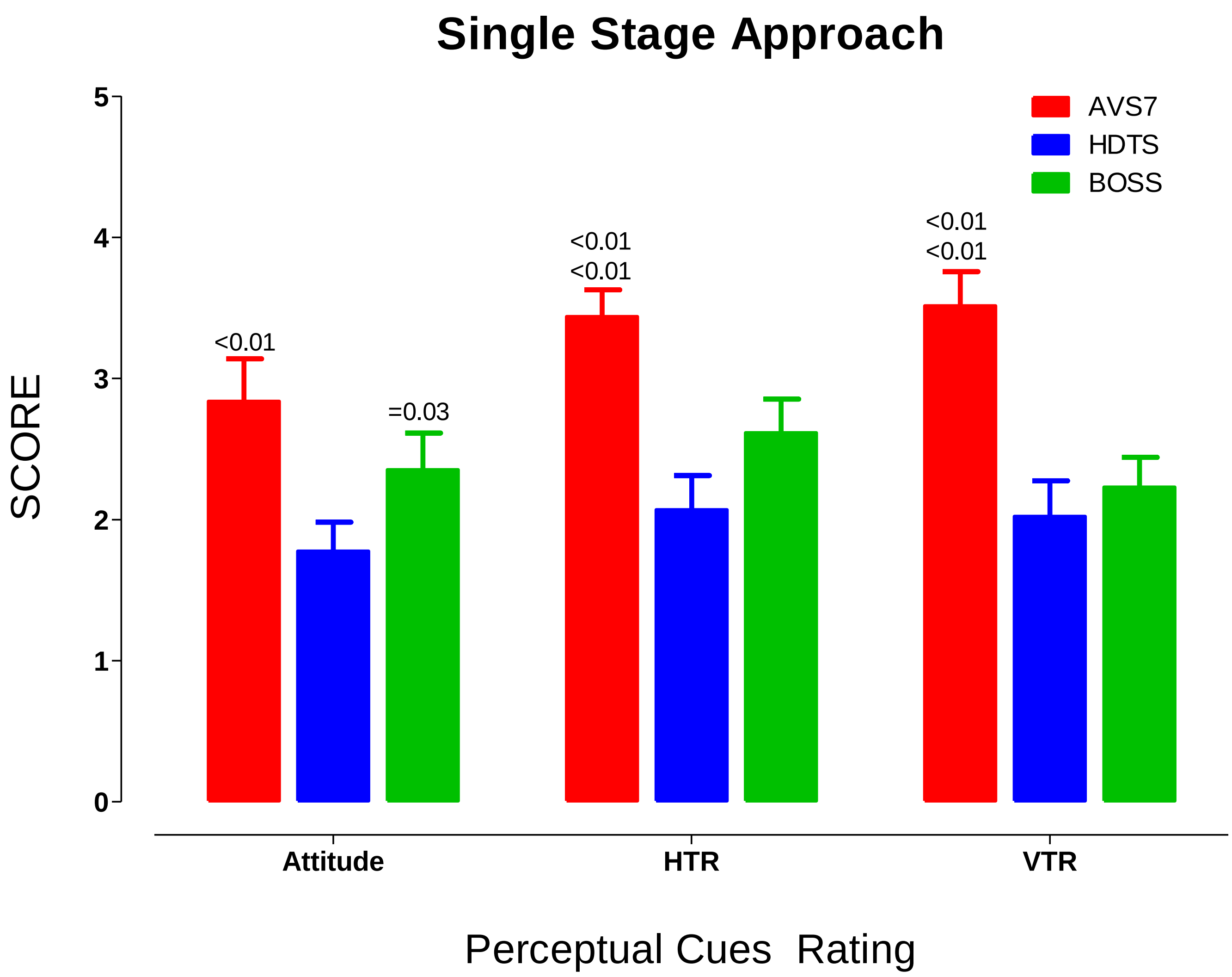
- 14 Griffon operational pilots (sim trial)
- 10 of the 14 participated in the flight trial
- Symbology systems
  - CH146 AN/AVS 7 (as baseline sim trial only)
  - HDTS-DVE
  - BOSS
- 5 Manoeuvres + 1
  1. Single stage approach
  2. Single stage departure
  3. Two-stage approach
  4. Hover turn
  5. Two-stage departure
  6. Re-designation of landing zone (for HDTS only)
- Total training time 210 min for sim trial, 90-96 min for flight trial
- Subjective and objective data were analyzed by 2 independent teams



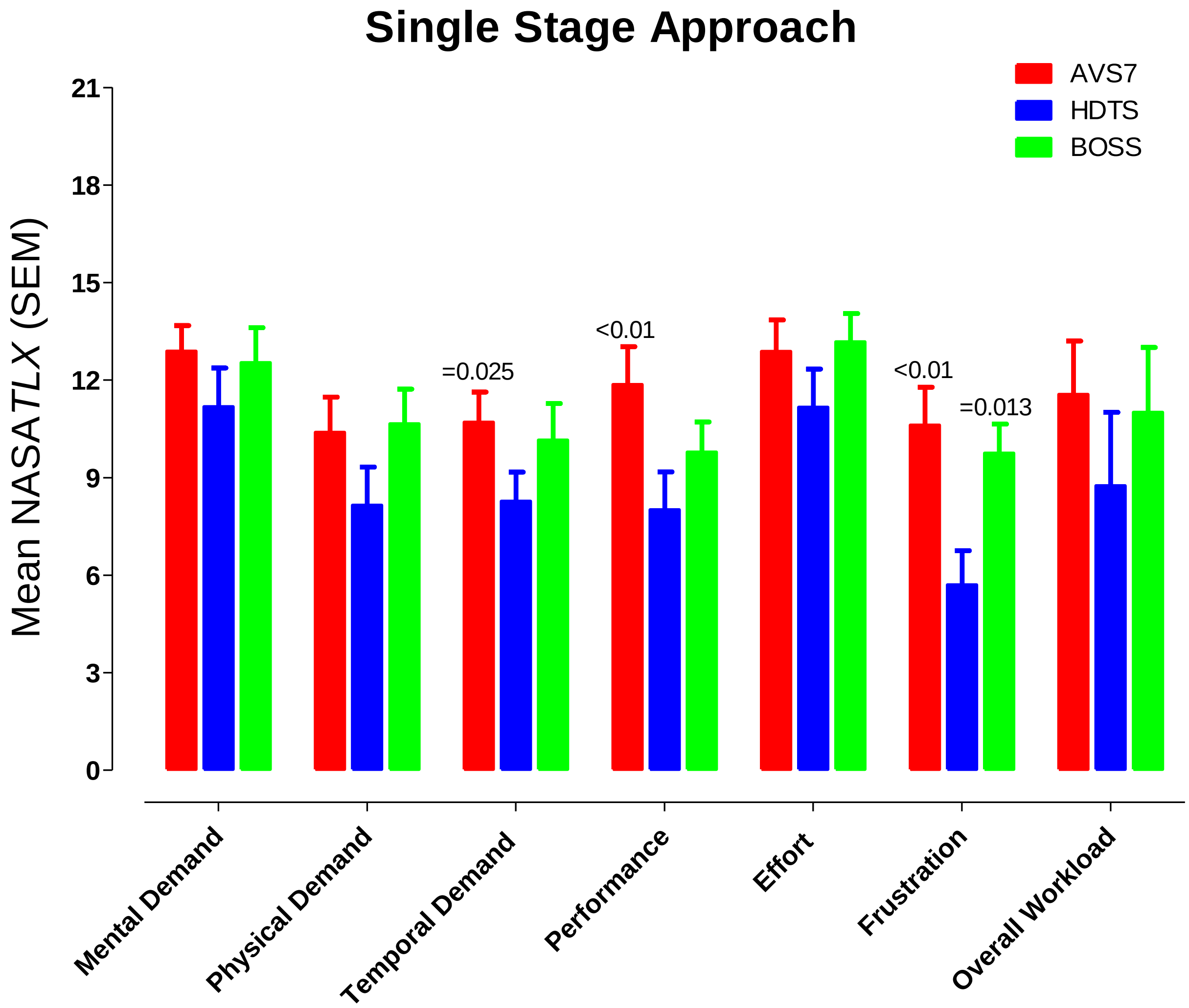
Subjective Results – SA, mental effort, perceived performance



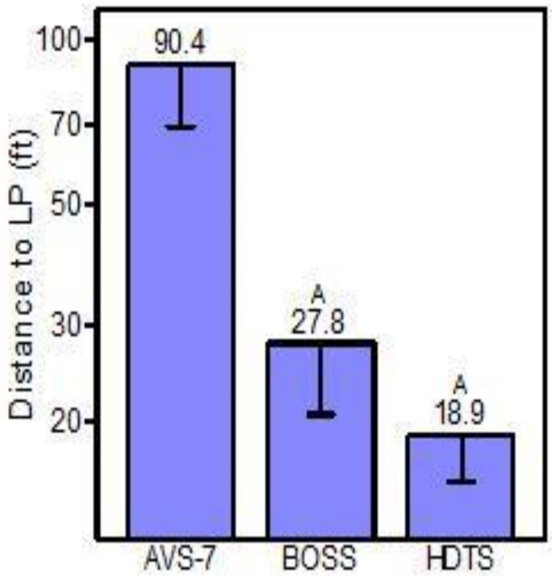
Perceptual Cue Rating

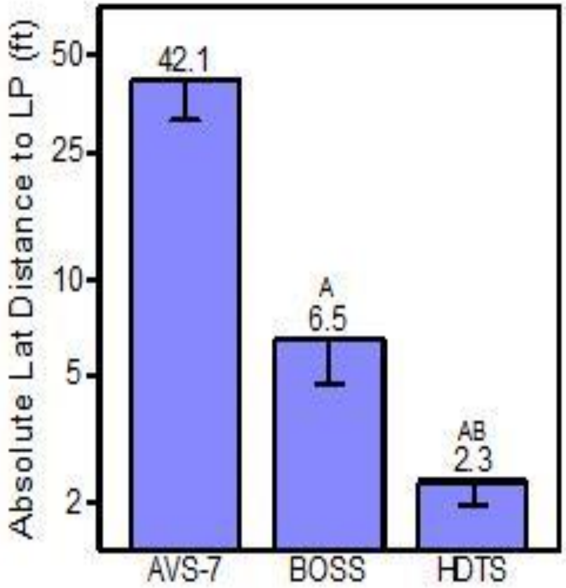


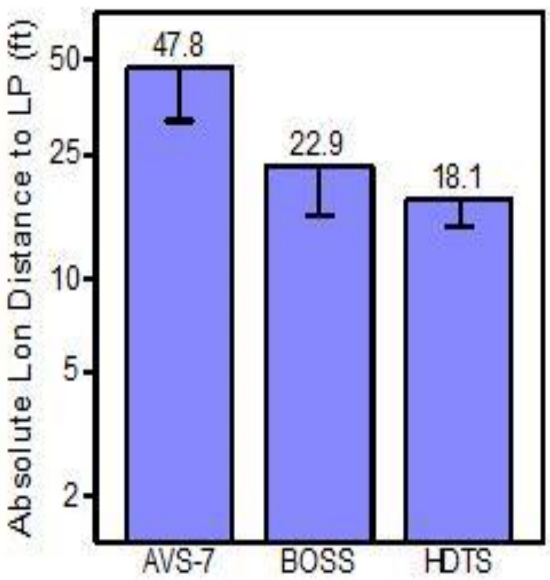
NASA-TLX


Single Stage Approach
AVS7
HDTS
BOSS
Mean NASATLX (SEM)
21
18
15
12
9
6
3
0
=0.025
<0.01
<0.01
=0.013
Mental Demand
Physical Demand
Temporal Demand
Performance
Effort
Frustration
Overall Workload

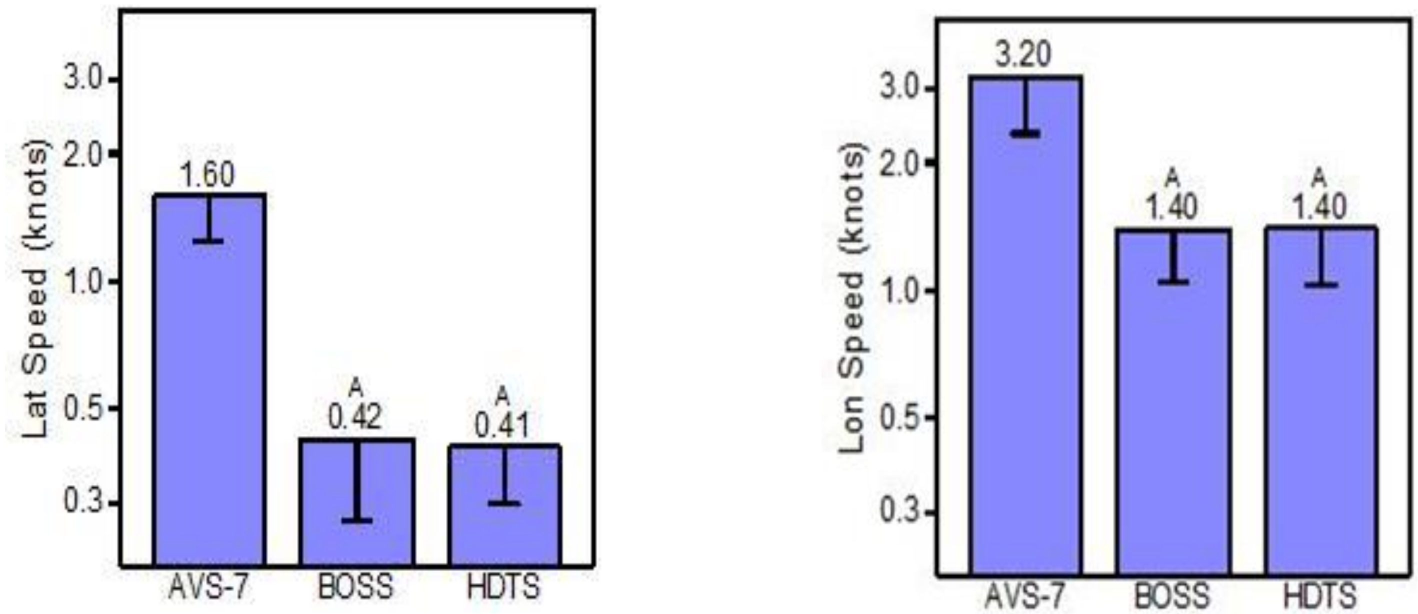
Distance to LP





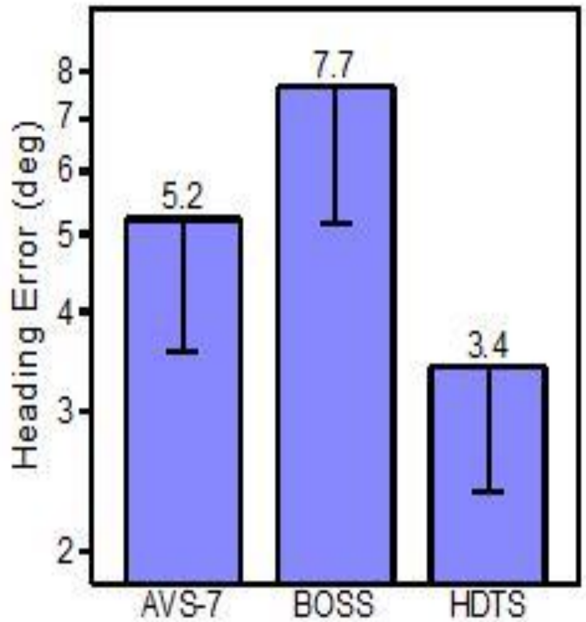


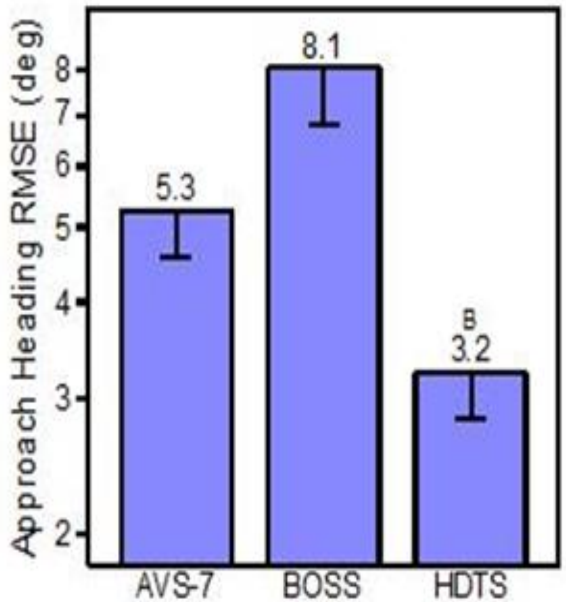
Lateral and Longitudinal Speed



Heading Error

RMSE - quadratic mean, is a statistical measure of the magnitude of a varying quantity



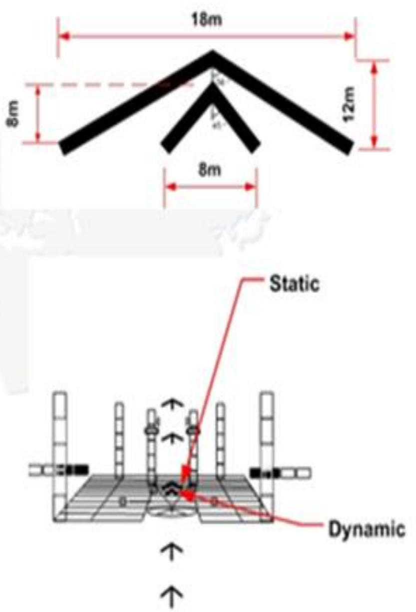


Improvements made in HDTS for landings

PARKING

Update – New Symbol

- Provides 3D virtual information about the A/C's position and heading relative to the exact LP location
- 3D Dog House
- **Shape:**
  - 2 Caret:
    - Static - locate in front of the two middles towers. Represent the desired location.
    - Dynamic – moves relative to the static caret represent the A/C's position and heading ("God View")
- **Motion:**
  - The dynamic Caret moves relative to the static one correlate with the A/C's position and heading relative to the LP location and the desired landing direction.
- **Hysteresis:**
  - Display below 0.05 nm



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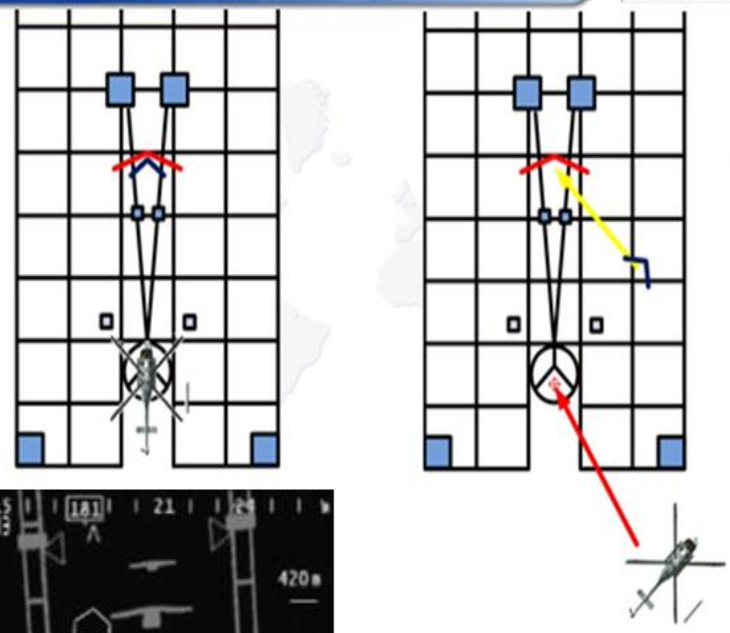
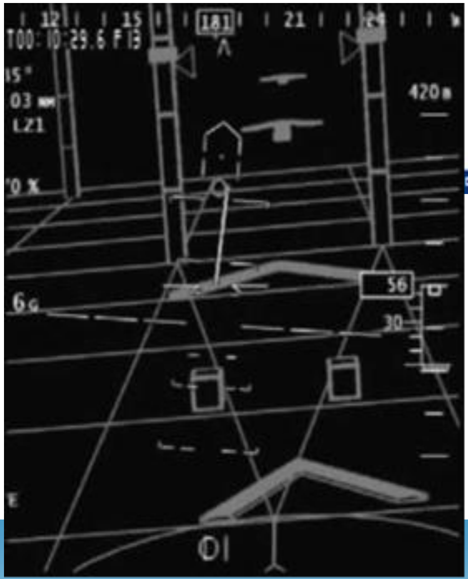
PARKING LOGIC





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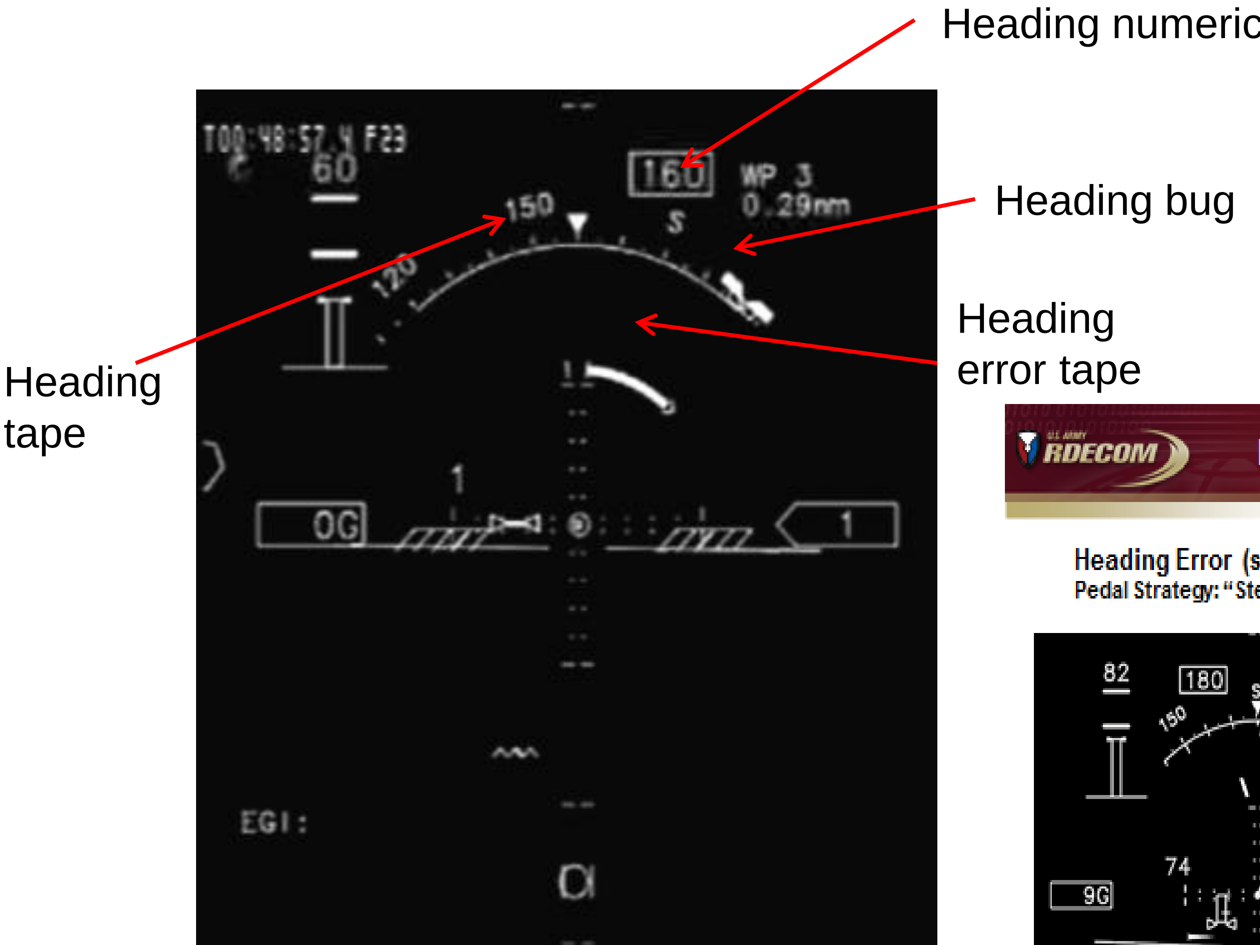
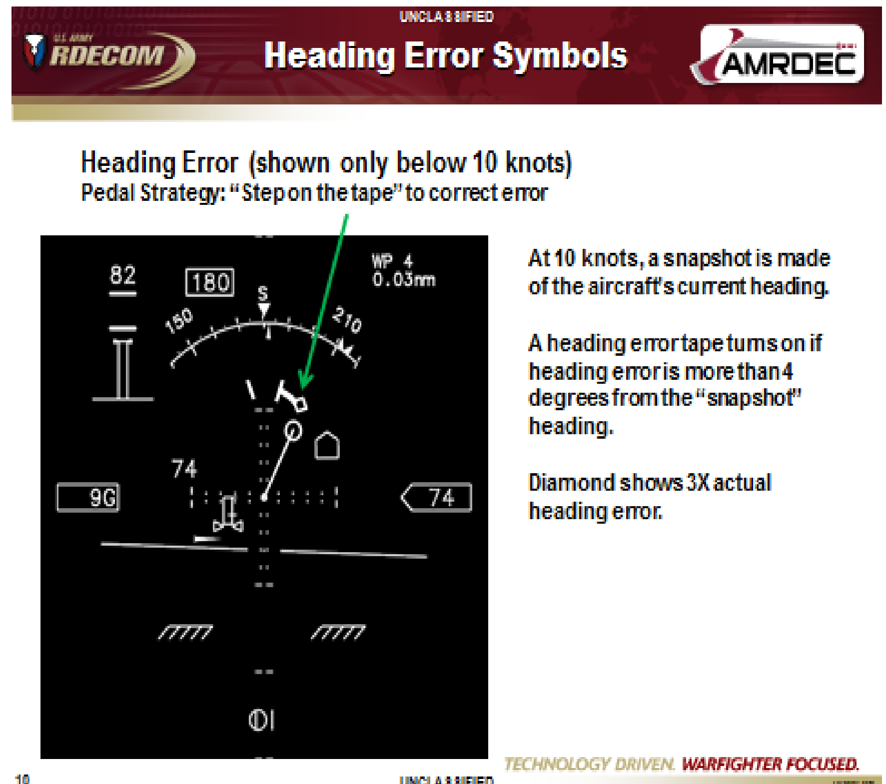
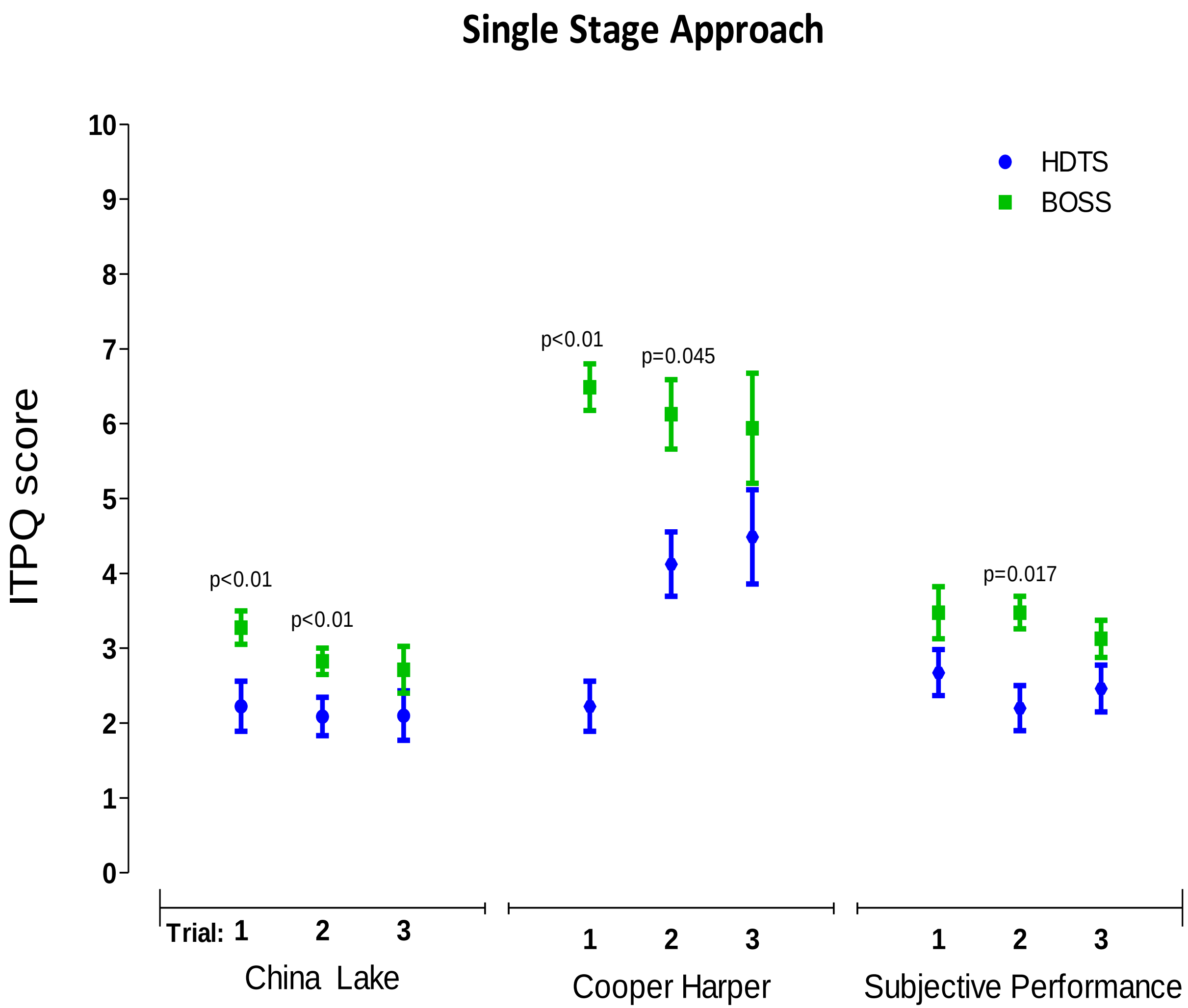


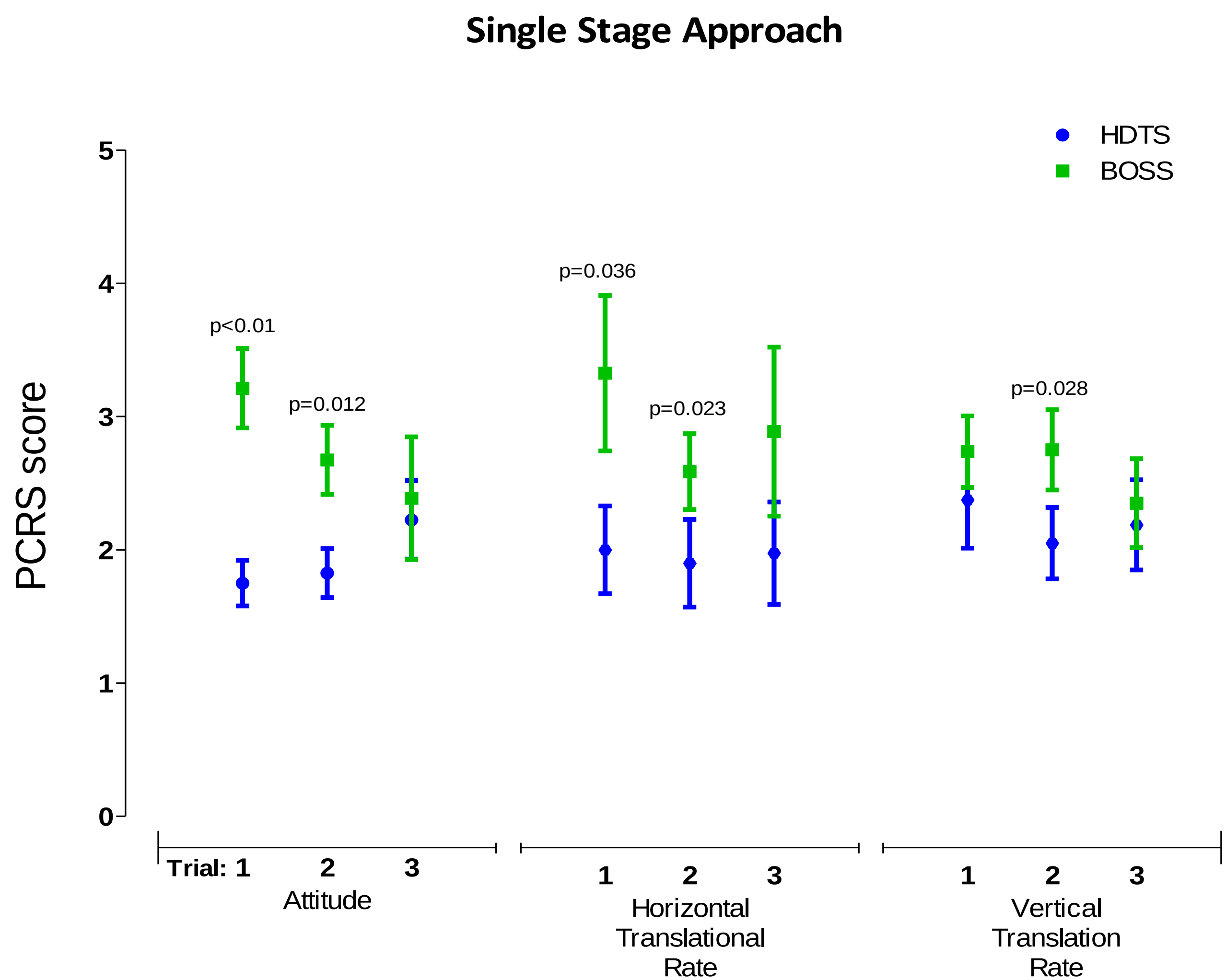
Improvements made to BOSS



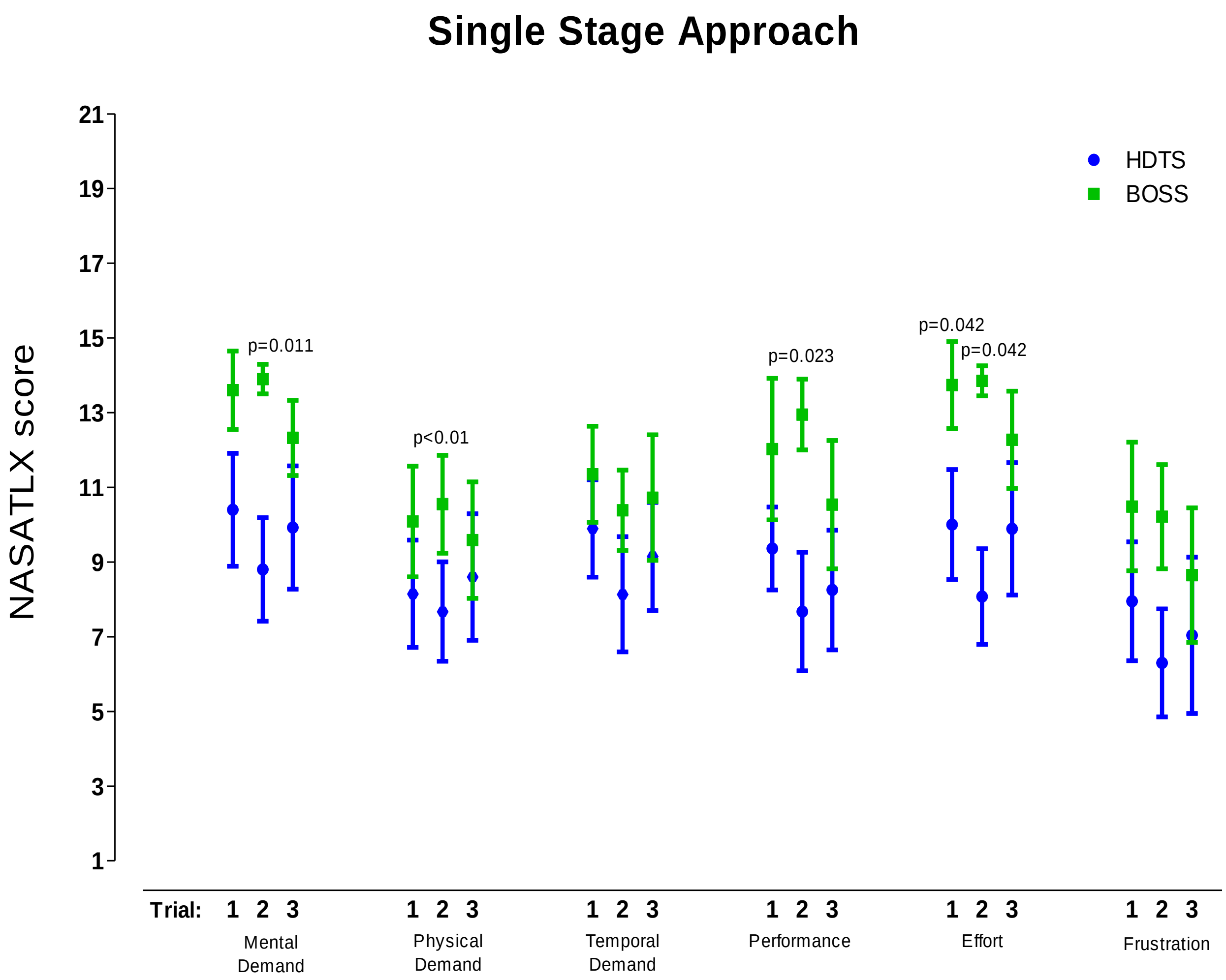
Subjective Results – SA, mental effort, perceived performance



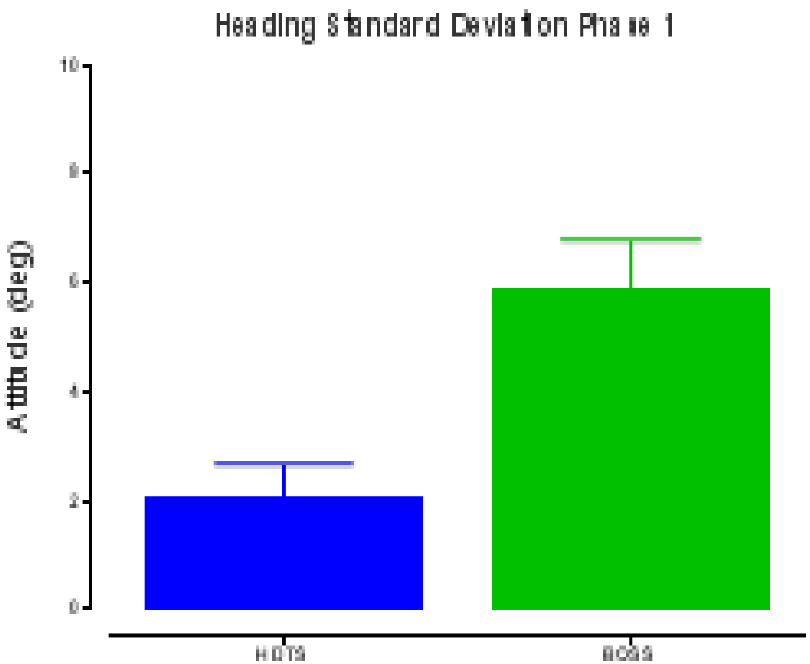
Perceptual Cue Rating

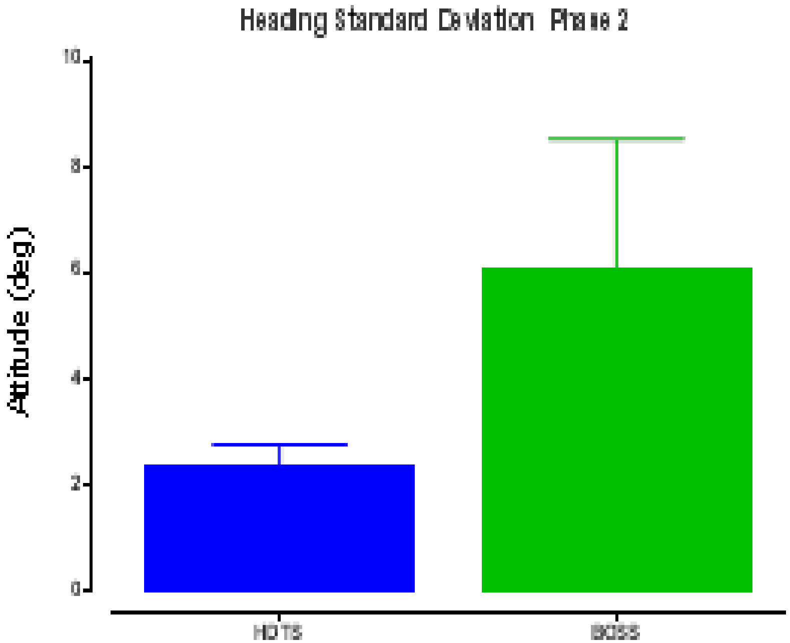


NASA-TLX


Single Stage Approach
NASATLX score
21
19
17
15
13
11
9
7
5
3
1
HDTS
BOSS
p=0.011
p<0.01
p=0.023
p=0.042
p=0.042
Trial:
1 2 3
Mental Demand
Physical Demand
Temporal Demand
Performance
Effort
Frustration

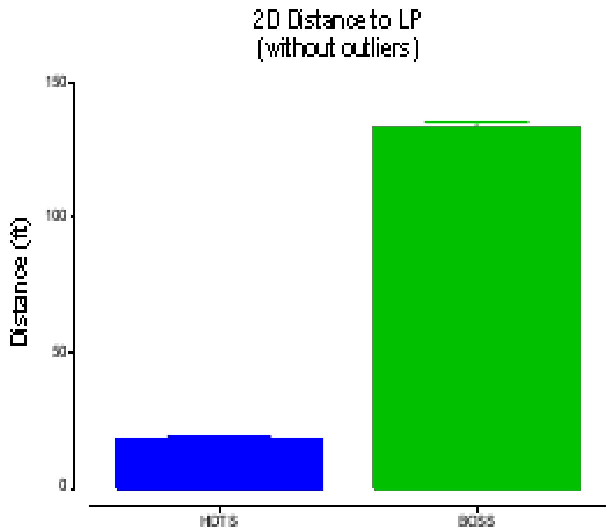
Objective Results - Single Stage Approach

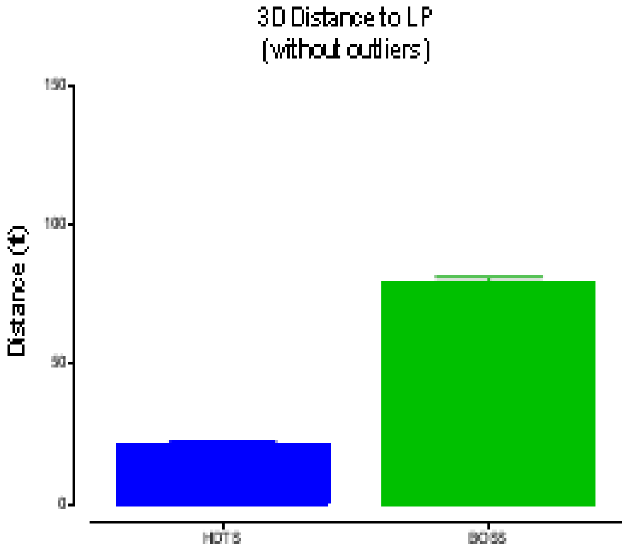


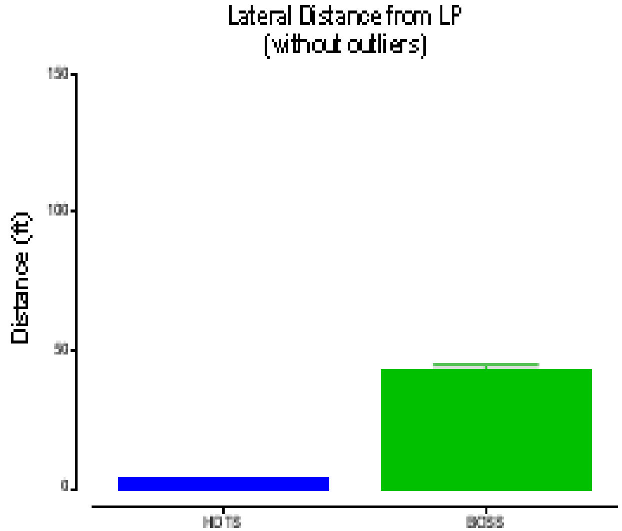


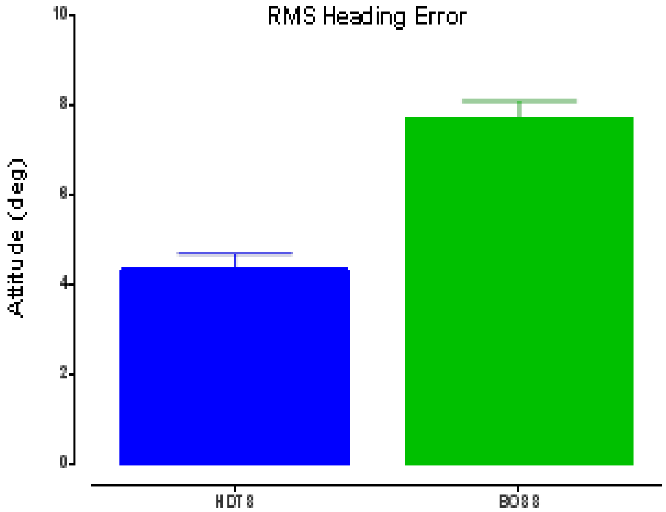
- Heading standard deviation difference $p < 0.012$ during phase 1 (between 0.7NM & 0.4NM) and $p < 0.001$ during phase 2 (between 0.4NM and end of flight)
- **Percentage of Successful landings made:**
  - **HDTS – 23 out of 27 = 85.1%**
  - **BOSS – 13 out of 27 = 46.1%**

Average Distance Offset and Heading Error from the Desired Landing Position (without outliers)

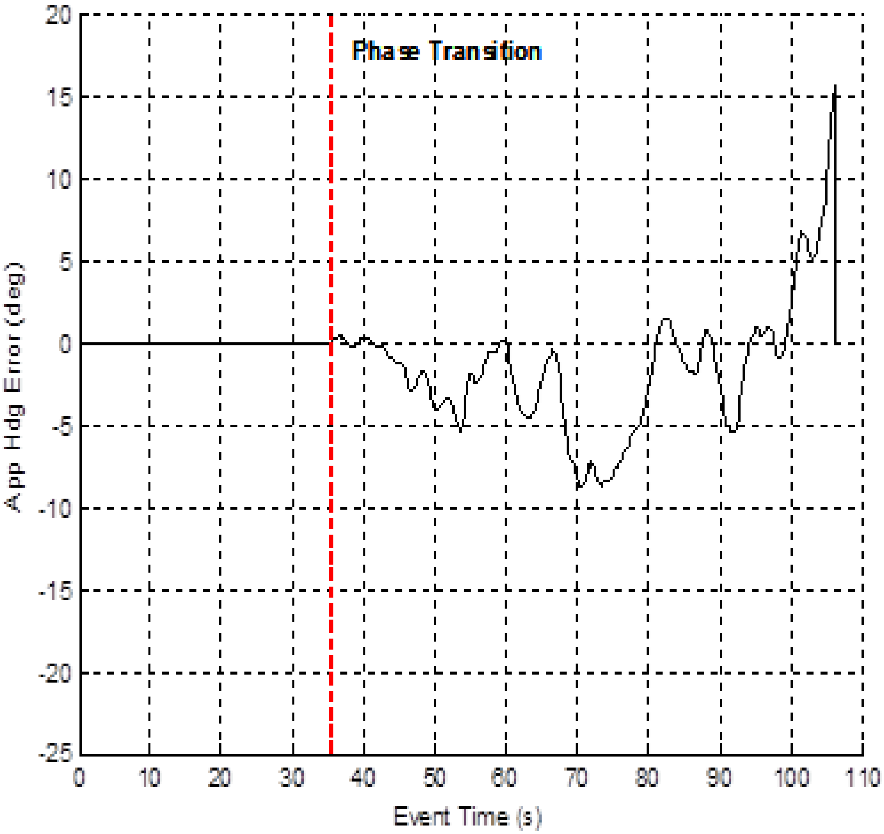


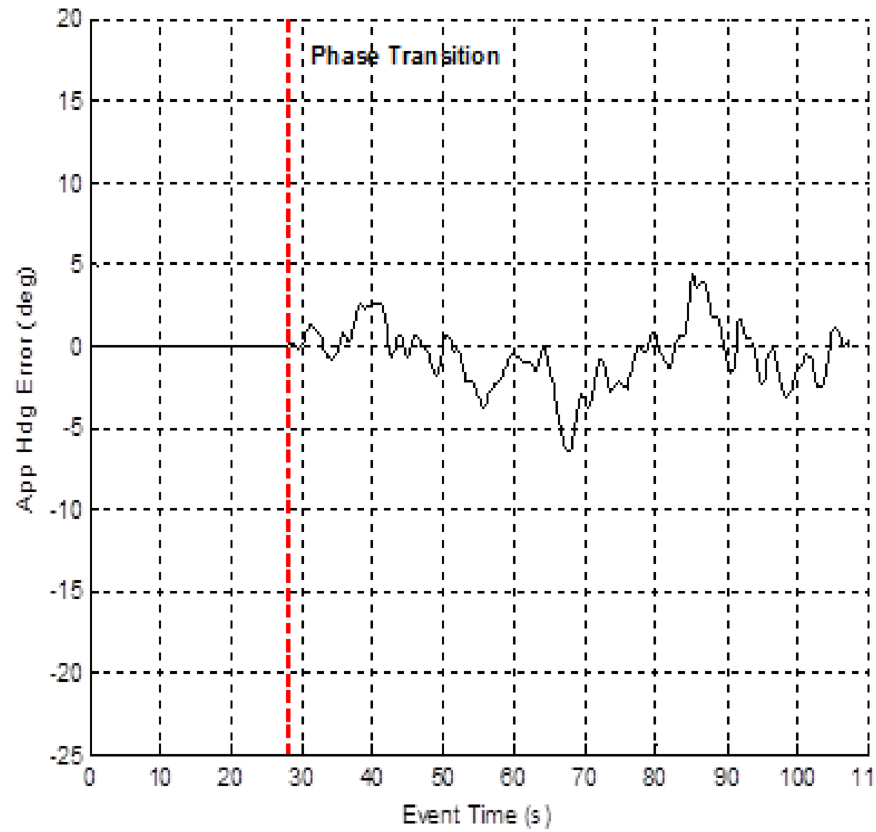






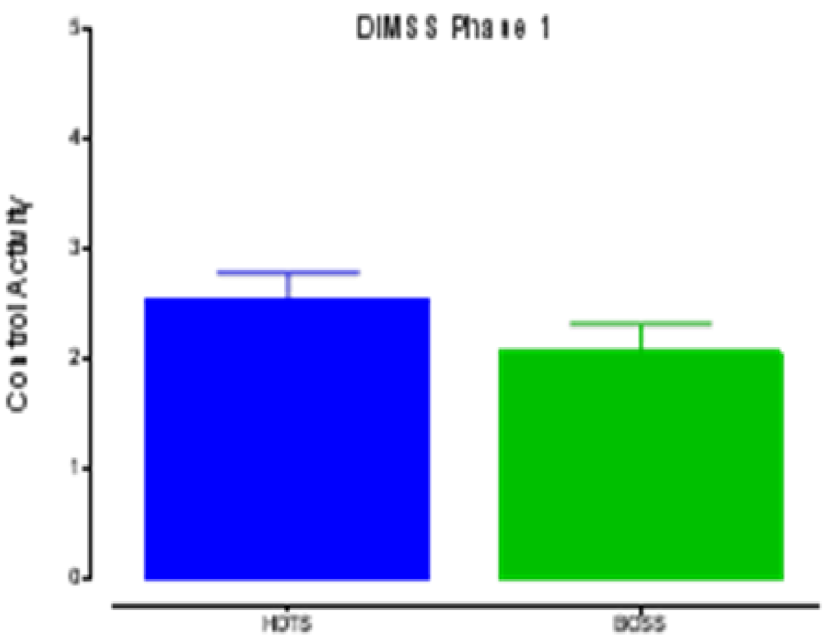
Sample plots for approach heading error from initial during Phase 2 (began at 0.4 NM back from the landing point) of BOSS (L plot) and HDTS (R plot)

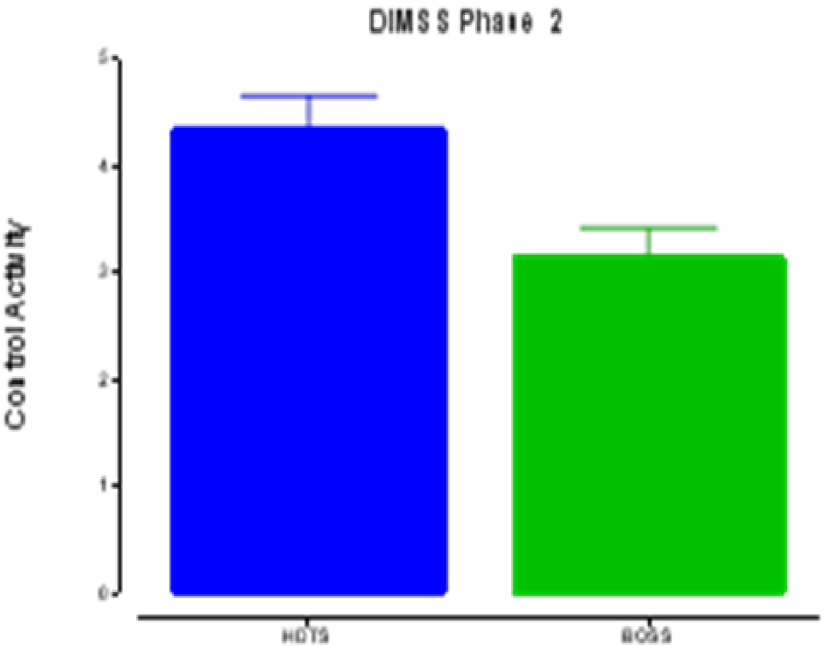




Dynamic Interface Modeling and Simulation System (DIMSS) Metric

- Assessing the control deflection (size) and a control reversal (max & min in the control deflection time history) that represent the amplitude and frequency of control movements
- Activity metric = number of control reversals x standard deviation of control movement within a moving 3s window
- Control activity difference - $p < 0.048$ during phase 1 (0.7 NM to 0.4 NM)
- Control activity - $p < 0.001$ during phase 2 (0.4 NM and end of engagement)





Direct quotes from pilots regarding HDTS

- *HDTS specifically the "towers" provide more comfort for the executed manoeuvres*
- *HDTS provided enough 3D cues such that it made for a very natural feel using typical helicopter references available during a VMC approach*
- *HDTS was very useful for all tasks but especially below translational lift (hover and fine position adjustment), the 3D reference was natural and as if I never lost visual reference*
- *HDTS provides 90% of what you need on the Griffon to execute the manoeuvres*

Direct quotes from pilots regarding BOSS

- *Prefer the BOSS for approach and information for the glideslope and speed but it was less useful in the hover work and landing.*
- *BOSS required more interpretation and understanding; it also required a different control strategy than HDTS or visual flying.*
- *There was no spare capacity available when using BOSS, if the results were off, SA will break down compounding the error.*
- *In the hover, there was too much information to scan and digest, it is difficult to interpret position, heading and altitude at the same time.*


12
15
186
21
24
W
L21
520
195
180
150
120
90
E

Conclusion

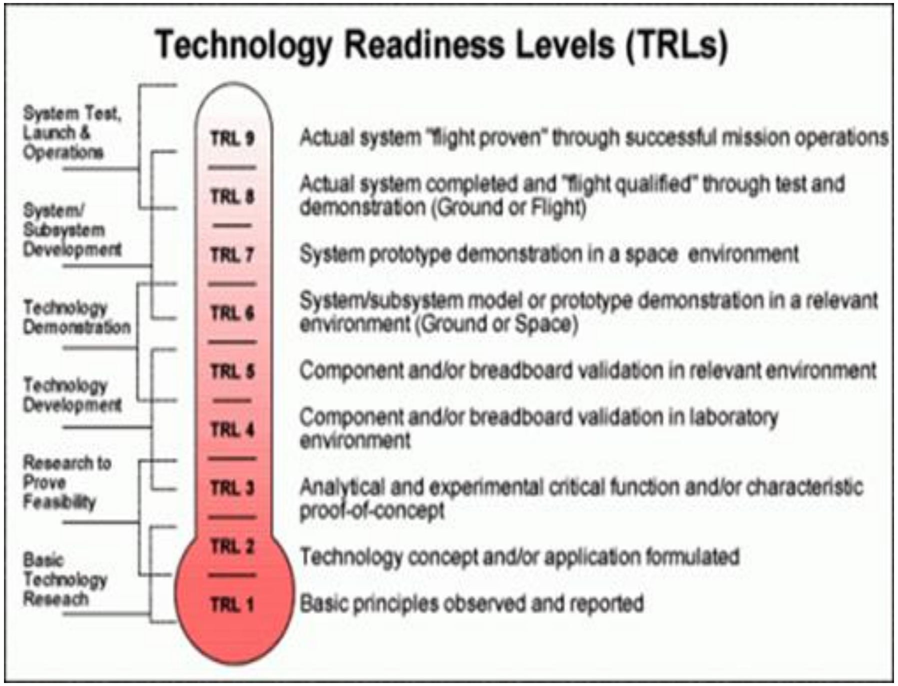
- 2D (BOSS) symbology provides good precision in locating spatial surroundings
  - The added requirement of interpretation demands more attentional and cognitive loads and prone to attentional capture
  - Resulting in undesirable perceptual fixation on specific symbol
  - Disruption of normal scanning patterns

- Conformal symbology (HDTS) was able to accommodate dividing attention
  - Attention was afforded to both the conformal runway symbol and its far domain counterpart
  - Allows efficient allocation of attentional resources to lateral, longitudinal and vertical information during the critical phases of flight
  - Symbologies were intuitive

Recommendations

Implementation of a helmet mounted HUD conformal symbology system for critical phases of flight in DVE

- Phase 1 - Implementation of HDTS system for operational evaluation (further modification and control strategy development) and to reach TRL-9
- Phase 2 – (concurrent with Phase 1)
  - Further investigation of appropriate sensor technologies for various phases of flight in DVE
  - Integration of flight symbology displays with appropriate sensor suite and
  - Evaluation of the combined system



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- RCAF pilots - Maj Rhett Chambers, Maj Francois Dufault, LCol Peter Fedak, Capt Jay Walker, Maj Michel Gratton, Maj Frederic Cote, Capt Andrew Foster, Capt Jan Wesselo, Capt Tommy Villeneuve, Capt Jeffrey Beaudry and Capt Michael Jordan.
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- DRDC Toronto, JOHSC - WO Chris Townson, Sgt Allison Riddell.

Pertinent References

- Bob Cheung, Andy McKinley, Brad Steels, Robert Sceviour, Vaughn Cosman, Sion Jennings, Peter Holst (2015) Simulator Study of Helmet Mounted Symbology System Concepts in Degraded Visual Environment. Aerospace Medicine and Human Performance 86 (7), July 2015 588-598

- Bob Cheung, Greg Craig, Brad Steels, Robert Sceviour, Vaughn Cosman, Sion Jennings, Peter Holst (2015) In-Flight Study of Helmet Mounted Symbology System Concepts in Degraded Visual Environment Aerospace Medicine and Human Performance 86 (8), August 2015 714-722

- Bob Cheung, Andy McKinley, Brad Steels, Rob Sceviour, Vaughn Cosman, Peter Holst (2014) Degraded visual environment solution for tactical helicopter Part 1– simulator investigation. Final Report to Directorate of Air Requirement for Tactical Helicopter (DAR-9)

- Bob Cheung, Gregory Craig, Brad Steels, Rob Sceviour, Vaughn Cosman, Sion Jennings, Peter Holst (2014) Degraded visual environment solution for tactical helicopter Part 2 – in-flight investigation. Final Report to Directorate of Air Requirement for Tactical Helicopter (DAR-9)

Questions?