U.S. AIR FORCE

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Operational Based Vision Assessment (OBVA) "Human Vision Issues, Research and Future Research of the F-35 HMD"

23 Mar 2022

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711 HPW/RHBC

Headquarters U.S. Air Force

Integrity - Service - Excellence

HMD Update

Operational Based Vision Assessment Lab

RAMS/NATO STO HFM-350 Technical Course

23 Mar 2022

AIR FORCE MEDICINE

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Disclaimer

- The views expressed are those of the author and do not necessarily reflect the official policy or position of the Air Force, the Department of Defense, or the U.S. Government
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- Off label use of medications will not be discussed

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F-35 Helmet Mounted Display System (HMDS)

- 2014 Air Force Medical Service (AFMS) Gaps
- JPO White Paper (Optical Challenges, Feb 2014)
  - F-35 HMDS, and emerging HMD technologies, continue to require significant research

AFMS Priority	Sponsor	Criteria	Initiative	Description	AFMS Strategic Objective	JPC Alignment
3 (of 85)	ACC	A	**Tactical Sensing**	Identify measurable specifications and interpret the MILSTD requirements related to pilot vision standards, fields of view, levels of glare, HSI for weapons employment, situational awareness and flight safety. (Employment of the F-35 with it's unique PVI and sensors (i.e. new helmets))	A2, E4	JPC 5

"…. Identify measurable specifications and interpret the MILSTD requirements related to pilot vision standards, fields of view, levels of glare, HSI for weapons employment, situational awareness and flight safety. (Employment of the F-35 with it's unique PVI and sensors (i.e. new helmets))

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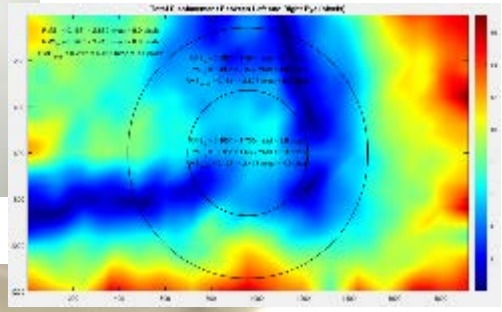
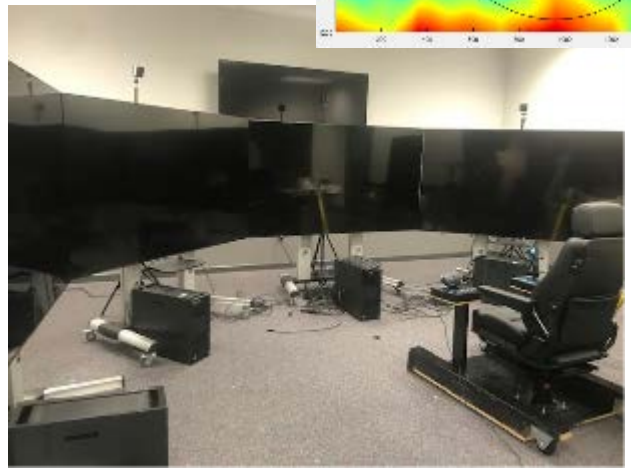
OBVA HMD Laboratory Capabilities

- HMD measurements
  - Alignment, luminance, FOV, etc.
- Magnetic and Optical head tracking
- Christie StIM projector
  - Night Vision IR display stimulation
- 5 x 85” 4K color screen mobile display
- In-house symbology research software
  - Leveraged previous 711HPW/RHC development
- Diamond Visionics & X-Plane image generation systems
- Multiple HMD systems
  - F-35 Aircraft HMDS (no NVC)
  - SA-62S Transparent Color OLED
  - SA-52 Opaque Color OLED
  - HTC Vive





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Partners & Collaborations

VISION PRODUCTS

- Misalignment measurements of fielded F-35 HMDS
- Bob Foote, CA (ret) F-35 designer

Collins Aerospace

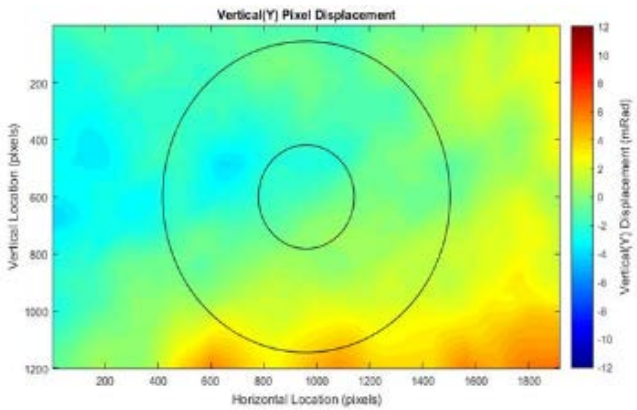
- CRADA in place
- Identify future research areas with ongoing HMD developments

NAVAL MEDICAL RESEARCH UNIT NAMRU DAYTON

- Effect of reduced oxygen on binocular vision

Magic Leap

- Developing CRADA
- Utility of embedded eye-tracking
- Exploratory VR use (e.g. alternative RVS display, vision testing device)



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F-35 HMD and Previous OBVA HMD research

Helmet Mounted Displays

Monocular: One image to one eye

Biocular: The same image to each eye

Binocular: Two different images to each eye

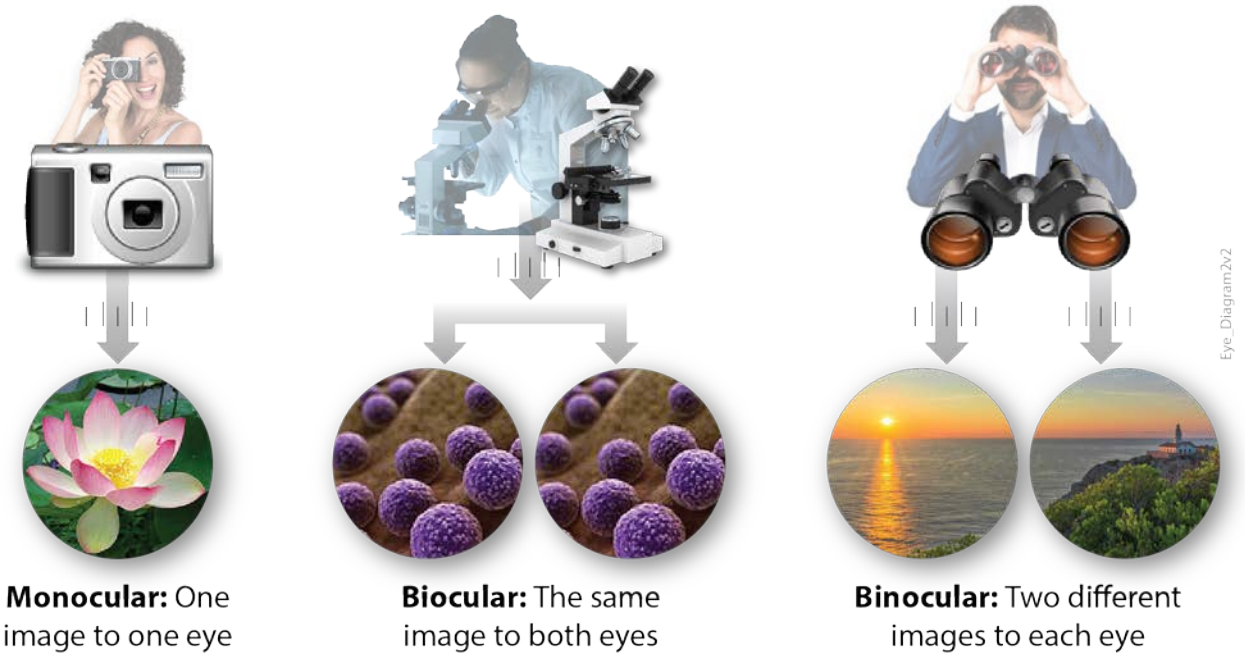

Image created by OBVA personnel

Potential benefits to **'Binocular':**

→Decluttering information (Kooi, 2011)

→ Improving search times (Reis *et al.* 2008)

→ Reducing response times (Blake *et al.* 1981)

→ More efficiently capturing attention (Sakata *et al.* 2017)

→ Reducing perceived workload (Sakata *et al.* 2017)

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35 HMDS Background

- F-35 was the first aircraft to use a Head-Mounted Display System (HMDS) as primary flight instrument. Current version is Gen III+ & Gen III Light
- Every F-35 pilot is issued one HMD. He wears the same helmet for every test, training and operational mission. If the HMD is broken, they don't fly
- The Helmet is individually custom fit to each pilot.
  - Adjustment to HMDS is completed at Eglin or Luke AFB over a two day period and re-adjusted as required by Lockheed Martin personnel
  - Many pilots have required multiple readjustments due to vision issues
- HMD integrates Forward Looking Infra Red (FLIR) and Distributed Aperture System (DAS) imaging, night vision (ICES 11) and a virtual HUD.
- Flight/weapon aiming information projected onto a virtual HUD on the visor
- Different forward flight symbology and off axis targeting symbology

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Requirements

- **F-35 JPO white paper identified seven primary HMD issues requiring research:**
  - **Green glow**
  - **Double vision**
  - **Jitter**
  - **Monocular symbology**
  - **Canopy interactions**
  - **Symbology readability**
  - **HMD focus distance**

Four topics were selected for their emphasis on human performance that may be related to USAF vision standards and screening

Initial Research completed and transitioned to JPO, F-35 ACOI in 2018

Follow-on JPC-5 and J9 funded efforts to examine *emerging technologies* and *physiologic effects*:

- Stereo symbology
- Ocular fatigue
- Performance under hypoxic conditions

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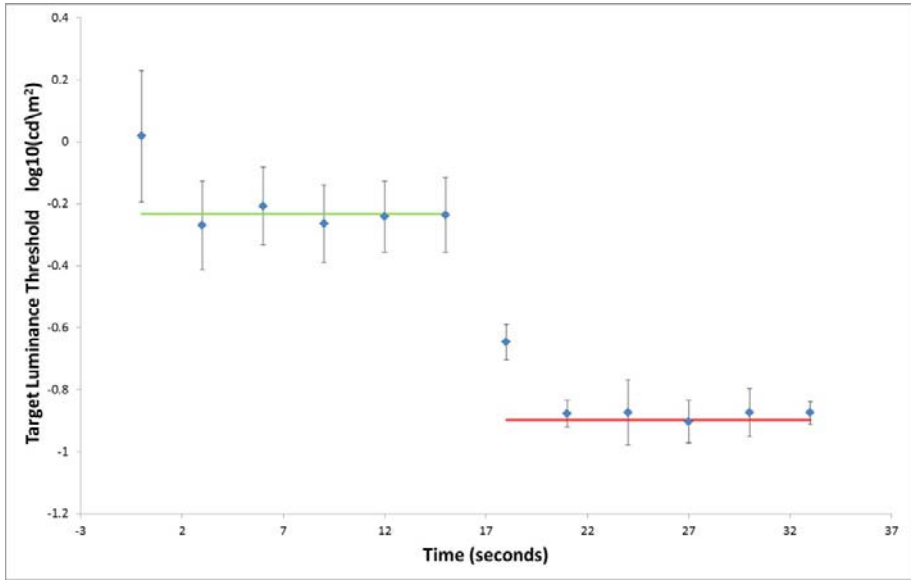
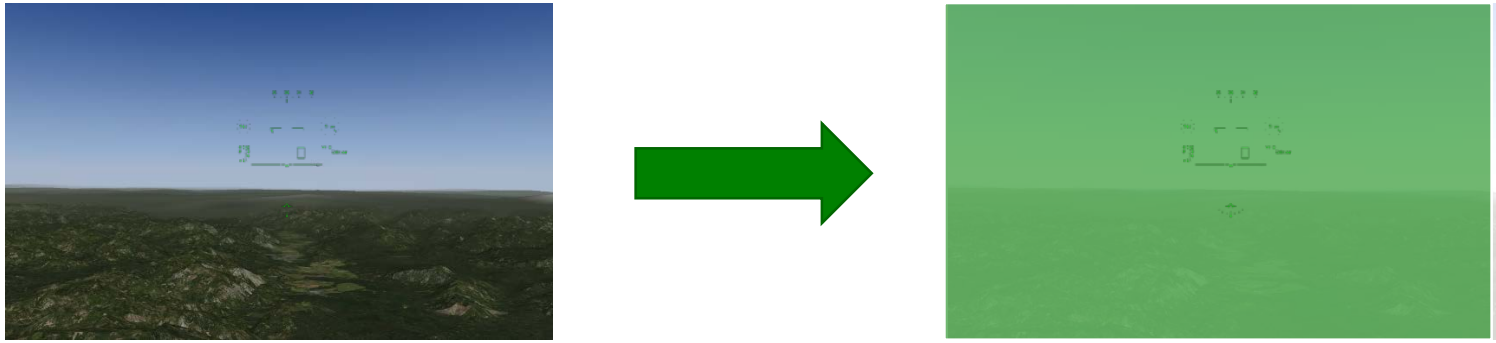
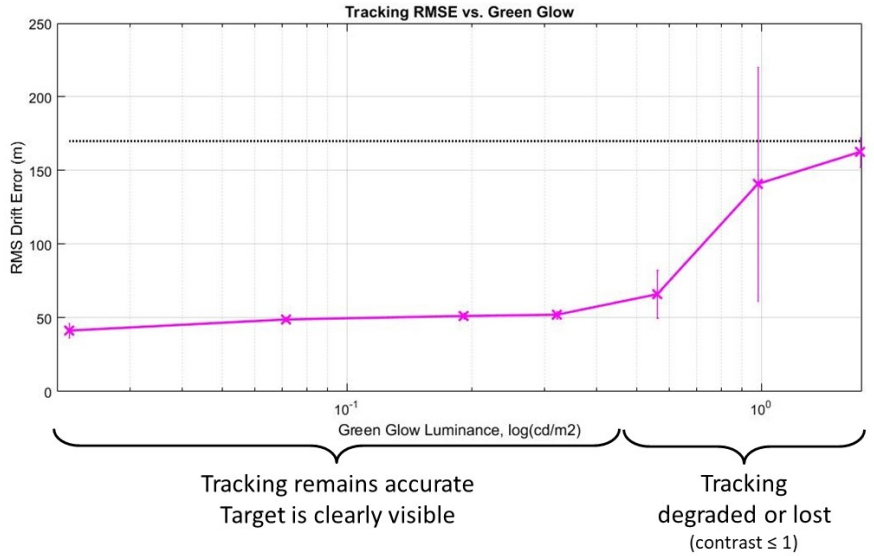
HMD Backlight “Green Glow”

- Quantified contrast thresholds, adaptation, recovery for varying green glow levels
  - Recovery time of a few seconds similar to that reported for viewing dim cockpit instruments after adapting to NVG green glow (Howard et al, 2001)
- Impact of green glow on aircraft following task (e.g. joining tanker)



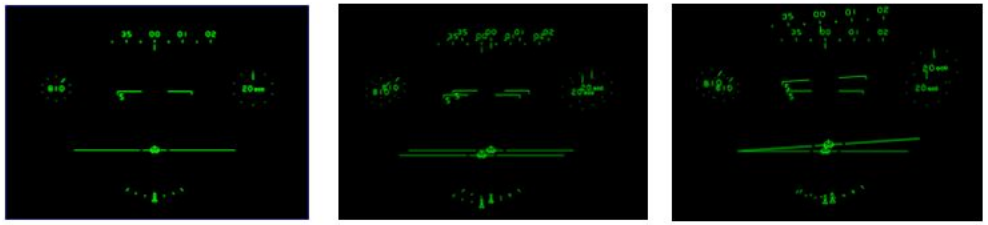




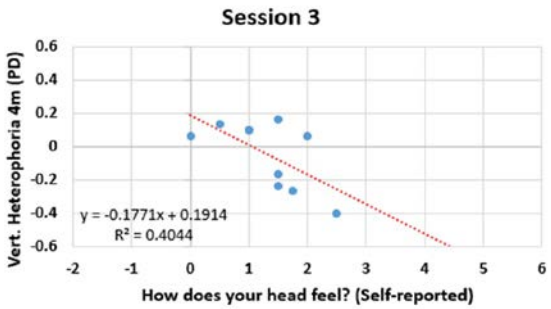
Howard, C., Riegler, J., and Martin, J. (2001). Light Adaptation: Night Vision Goggle Effect On Cockpit Instrument Reading Time. Aviation, Space, and Environmental Medicine, 72 (6).

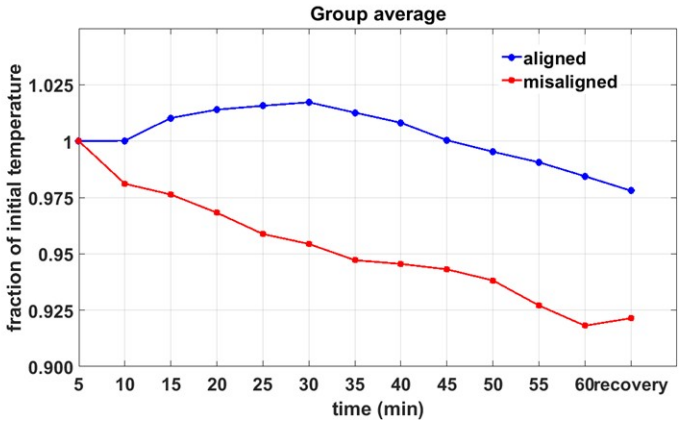
HMD Misalignment

- Effect of misalignment of symbology
  - Simulated HMD misalignment + canopy distortion
  - Phoria, fusion range measures correlated with self-reported fatigue, discomfort
  - Thales Top Owl HMD – effect of misalignment of NVG imagery (Defence Science & Technology Group)
    - Degraded task performance with misalignment



Well Aligned | Vertical & Horizontal Misalignment | Rotational & Magnification Misalignment





Gavrilescu, M., Karas, R., Douglass, A., Abel, L., & Gibbs, P. (2019, May). Changes in physiological parameters induced by optical misalignment in night vision binocular devices. In Situation Awareness in Degraded Environments 2019 (Vol. 11019, p. 110190F). International Society for Optics and Photonics.

Williams, L., Palmer, E., Gaska, J., Winterbottom, M., O'Keefe, E., Shoda, E. and Hadley, S. (2019). Ocular Fatigue in Biocular Helmet-Mounted Displays. Presentation at the Aerospace Medical Association Annual Meeting, Las Vegas, NV.

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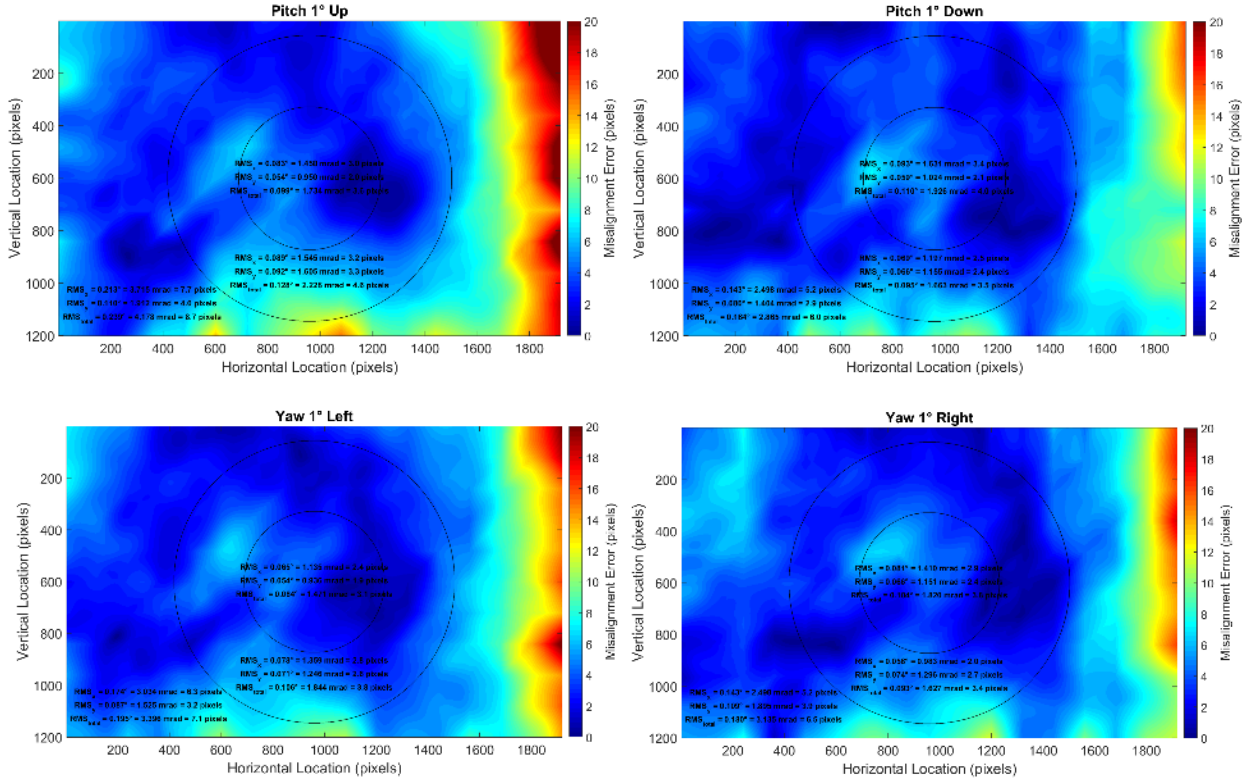
HMD Misalignment Measurement

- Developed proof of concept, deployable measurement system
- Successfully characterized COTS HMD (SA-62) and laboratory F-35 HMD
- Measurement system developed to quantify effects of varying IPD, gaze angle

Proof of concept, deployable HMD measurement system developed by OBVA Lab.



Relative misalignment with pitch 1° up (top, left), pitch 1° down (top, right), yaw 1° left (bottom, left), yaw 1° right (bottom, right).

Bauer, M., Williams, L., Nehmetallah, G., Van Atta, A., Gaska, J., Winterbottom, M., & Hadley, S. (2017). HMD distortion characterization and alignment toolset for precision-critical applications. In Degraded Environments: Sensing, Processing, and Display 2017 (Vol. 10197, p. 101970S). International Society for Optics and Photonics.

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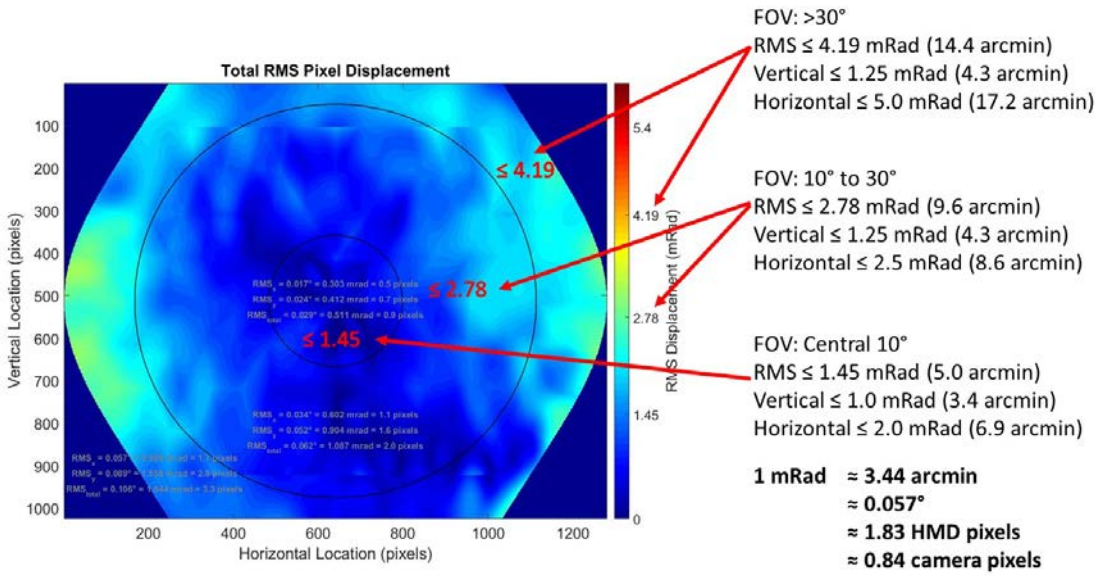
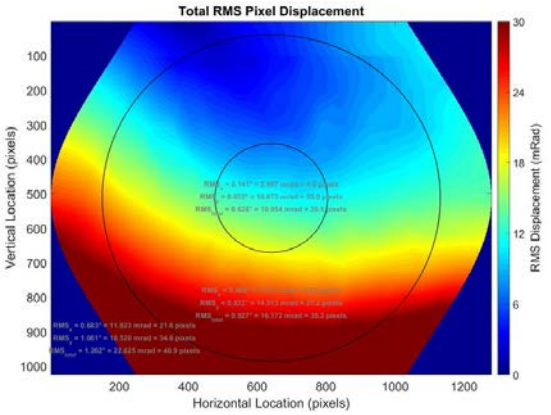
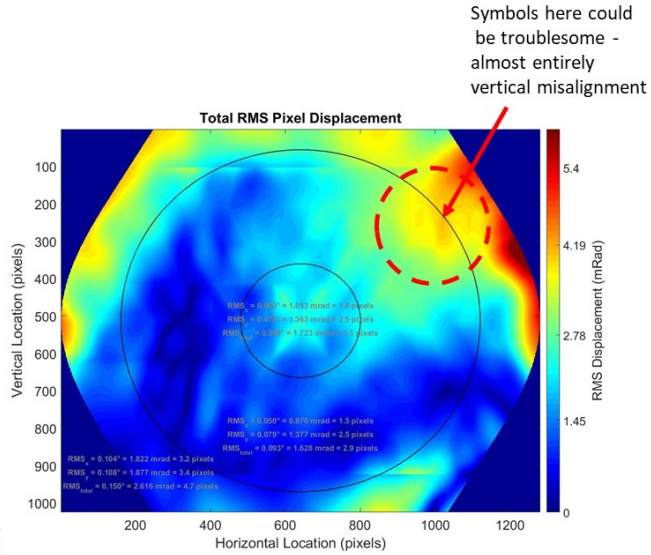
HMD Misalignment Measurement

- OBVA Laboratory F-35 HMDS measurements
- Measurements of OBVA Lab F-35 HMDS well-within specifications
- Variation in IPD, slippage, gaze angle
  - Introduces misalignment in periphery of FOV, but much of image still within spec
- Collins Aerospace interface hardware did not support measurement of fielded HMDs
- Continued R&D with SA Photonics



OBVA Laboratory F-35 HMDS measurements





Off-axis 15 degree gaze right (top right). Visor distortion (e.g. O2 mask touching visor, bottom left).

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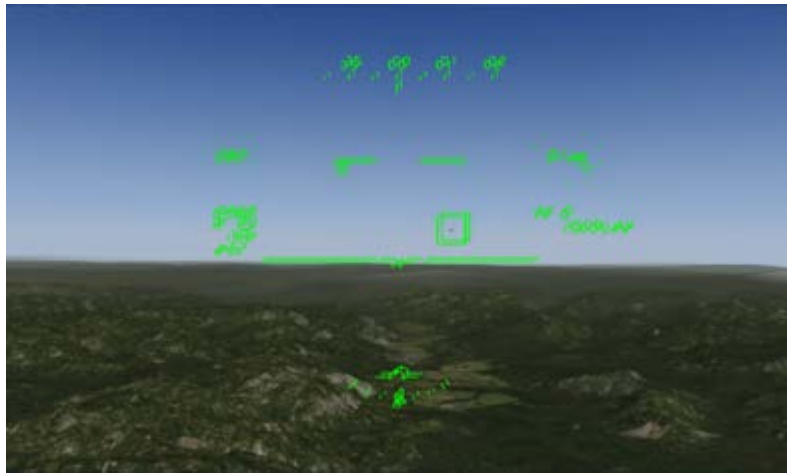
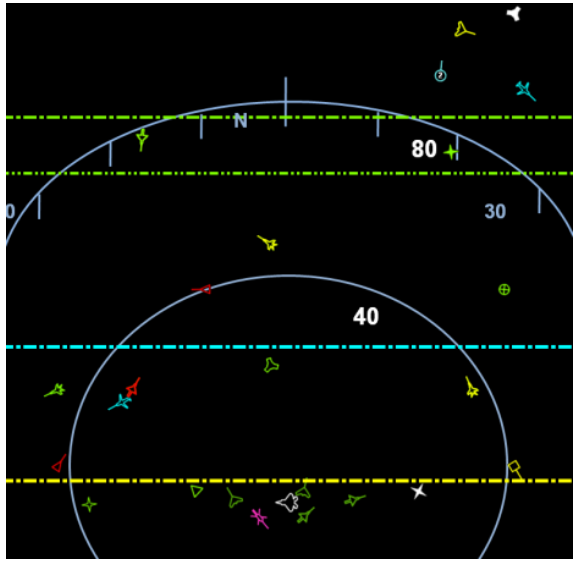
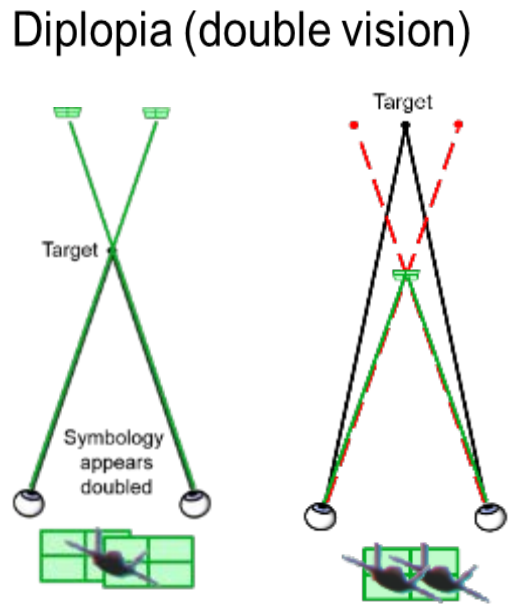
HMD Symbol & Distortion Research

- Effect of biocular symbol misalignment
  - When well-aligned, performance is **10%-20% better** with Biocular HMDS compared to monocular (throughput)
  - Individual ocular health (stereo acuity) determines the degree to which misalignment is noticeable
  - Slight misalignments reduce performance on some tasks more than others (e.g. search), but no worse than monocular
- Effect of optical distortions
  - Distortions reduce performance for all observers, for all conditions
- Poor horizontal fusion break & recovery ranges correlated with increased fatigue (self-reported visual clarity)







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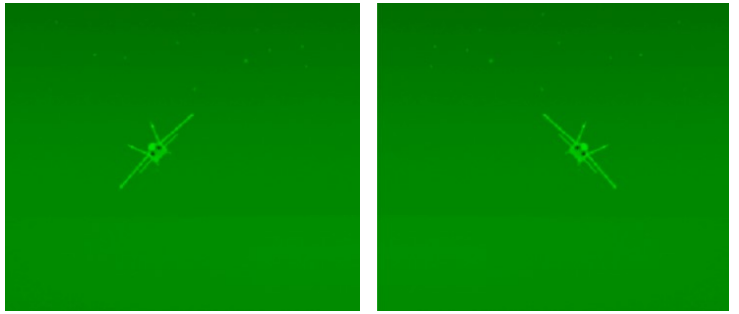
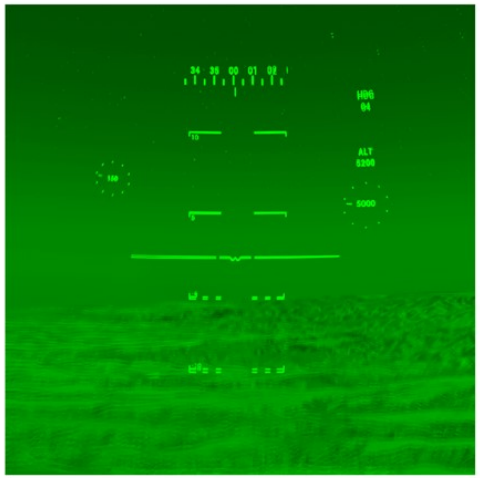
HMD Sensor Image Global Misalignment Pilot Study

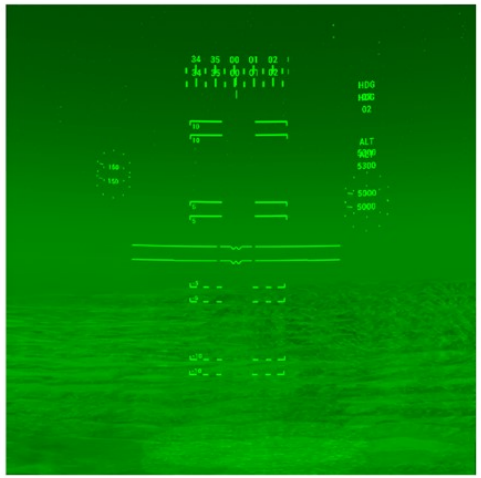
- Effect of HMD sensor image (DAS) misalignment on primary flight task (command heading, altitude)
- Misaligned imagery degraded air to air target discrimination
- Vertical image misalignment, but not roll misalignment, degraded primary flight task performance
- Diamond Visionics DAS Sensor Simulation, Head-tracked SA-62S HMD



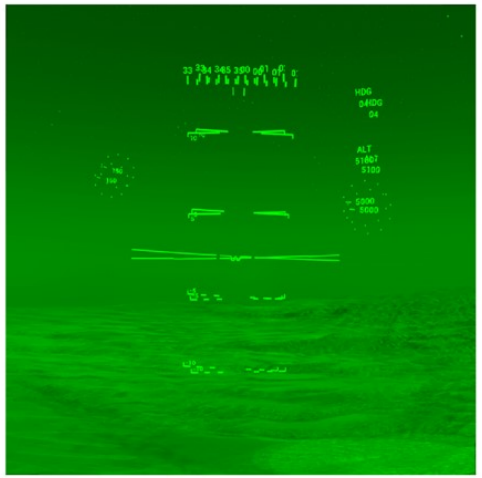
Aircraft target in simulated DAS



Well-aligned



0.67° Vertical Misalignment



4.0° Roll Misalignment

Address JPC-5 research objective: Joint DoD evidence-based medical criteria, standards and interventions to prevent and mitigate neurosensory and physiological degradation to aircrew.

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Extended-Reality Experimental Simulation Platform (XRES)

Head-tracking

- Steam VR Tracking
  - Steam VR 2.0 Base Stations
  - HTC Vive Tracker
  - HTC Vive VR System

Binocular HMD

- SA Photonics SA-62/S AR-HMD

Flight Control

- Unity 2019.3.0f6
- Saitek X-56 Rhino Joystick & Throttle

Out-the-window

- Diamond Visionics
  - Genesis IG 2.6.4.0
  - Genesis RTX 10.6.4.0
  - Genesis SN 1.2.0.10
- Samsung 85” Q70 QLED – 4k

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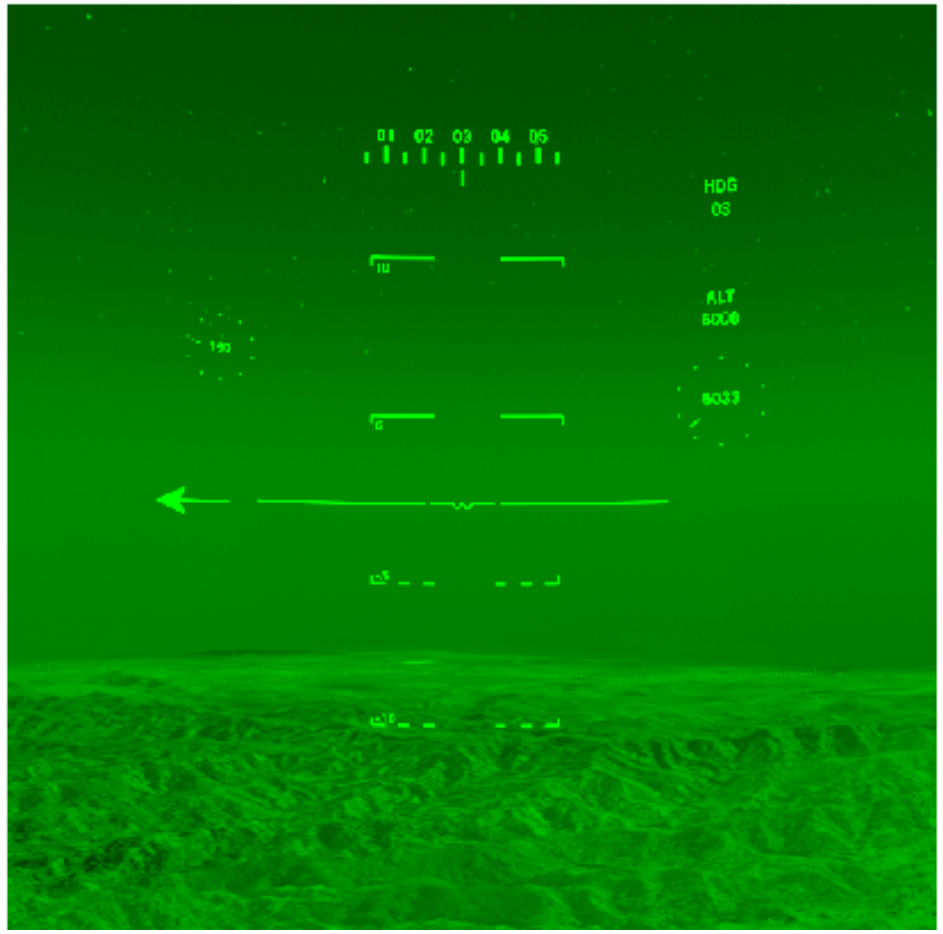
XRES Platform



Simulated sensor imagery and flight symbology in the HMD

AR Imagery

- Diamond Visionics Scene Imagery
  - REI UHDS-102 1x2 HDMI Splitter
  - Simulate sensor imagery (e.g. infrared, night vision device)
- Unity Overlay (HUD)
  - Fully customizable
  - Rapid prototyping

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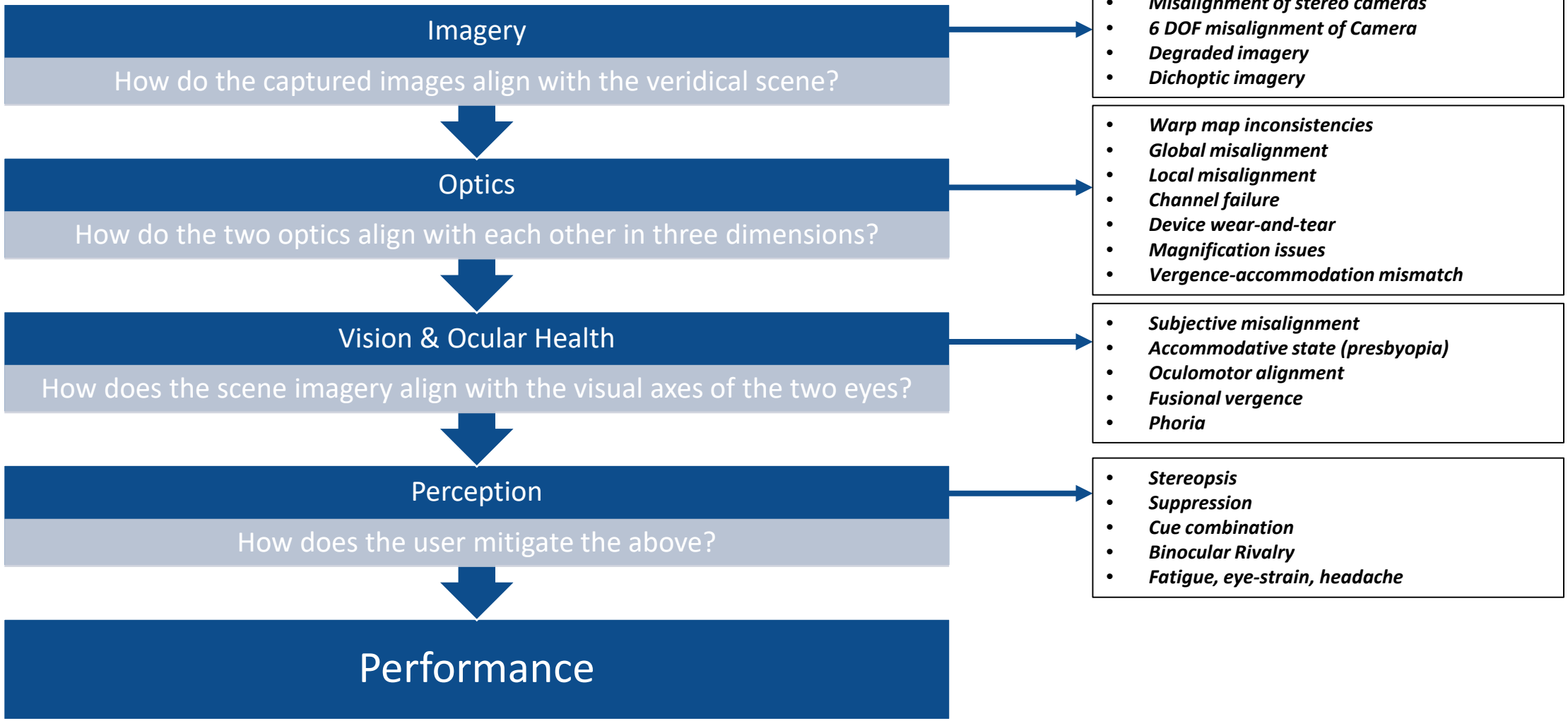
What all should we be aligning?



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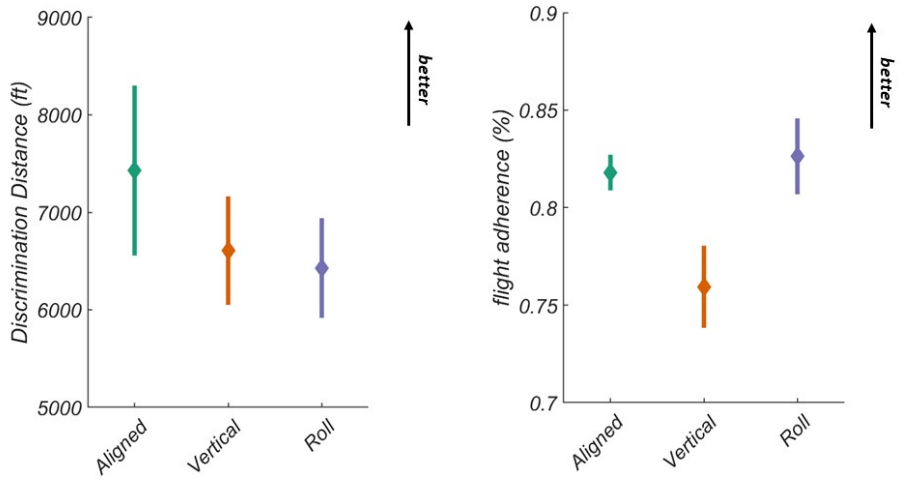
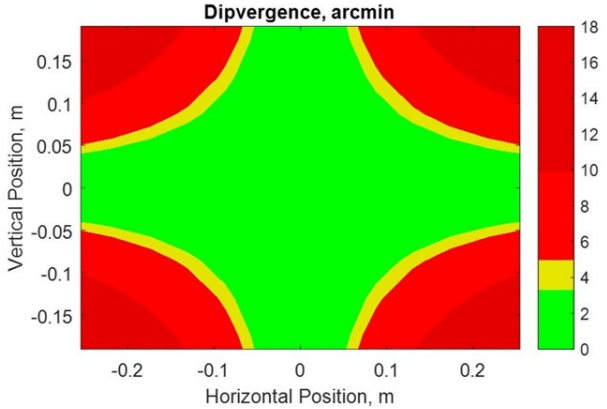
HMD Sensor Image Global Misalignment Pilot Study

- Preliminary results
  - Global image misalignment degraded aspect angle recognition range
  - Primary flight task degraded for vertical misalignment
- Future work
  - Replace global misalignment with representative F-35 HMD misalignment based on measurements of fielded helmets (varying local misalignment using warp map)
  - Evaluate combined effect of HMD and canopy distortion
  - Evaluation interaction of HMD/canopy distortion with individual ocular health and potential need for platform specific medical vision standard
  - Similar research with KC-46 RVS 1.0 distortions reveals individuals with poor stereo acuity, poor ocular alignment perform more poorly, more frequent headache, eyestrain



Global HMD image misalignment results. Effect on aircraft aspect angle range (left). Effect on primary flight task performance (right).



AVT & Experimental Tests		
	Correlation	Significance
Stereo	0.56	0.002
Min CS (all)	0.68	< 0.001
Min CS (< 30)	0.80	< 0.001
Fusion Range	0.70	< 0.001
Motion*	0.74	< 0.001
Dynamic Stereo	0.59	0.001

*Excluding 1 subject w/very poor CS

RVS 1.0 research. RVS 1.0 vertical misalignment (left). Correlation between simulated RVS refueling and vision (right).

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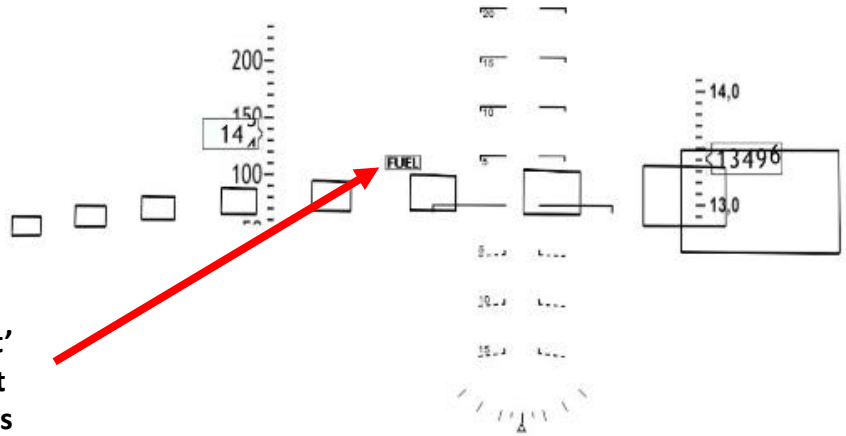
JPC-5 HMD Research

- Next generation HMDs could provide binocular imagery (stereo 3D)
  - Previous research suggests the addition of stereo 3D to a display can improve spatial awareness, depth perception, and performance in search related tasks.
- Investigated human performance using stereo 3D HMD, correlation with vision metrics
  - Previous research identified stereo warning task, 3D targeting symbol, and 3D highway in the sky based on interviews with pilot SME's



Task – To identify and differentiate FUEL/FLAP Warning symbol 'popped out' in stereo depth displayed in HMD, whilst flying the simulator to given co-ordinates

Browne MP, Moffitt K, Wimsatt C.(2017) "Stereo symbology concepts for Binocular Helmet-Mounted Displays" IMAGE 2017 Conference, Dayton OH.

Address JPC-5 research objective: Joint DoD evidence-based medical criteria, standards and interventions to prevent and mitigate neurosensory and physiological degradation to aircrew.

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Is stereo useful in HMD?

Next generation binocular HMD- Striker II

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- Mixed results of utility of stereo displays;
  - Steiner and Dotson (1990) – no benefit to using tactical information in depth in a simulated cockpit task
  - Browne, *et al.* (2017) – Improved response times in a warning symbol identification task during simulated flight
- Up to 30% of general population have deficient stereo acuity (Hess *et al.* 2015), and would not benefit from using stereo displays
- Lack of adequate measurement/screening of subjects' stereo acuity in previous studies (Sakata S. *et al.* 2017)
- Military stereo acuity standards, but test methods are crude and fallible. They remain unchanged despite advances in optical displays and complex visual tasks

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Research Questions

- How is human performance in a warning symbol task affected using S3D in a binocular HMD?
- Is individual stereo acuity related to any changes in performance?
- Would newer computer-based stereo acuity threshold tests be better predictors of performance?
- Are physiological workload measurements related to different stereo imagery conditions?

Null hypotheses

1. There is no difference in response time and throughput in a warning symbol task between stereo conditions
2. There is no relationship between stereo acuity and performance (in any condition)
3. The addition of stereo to a display does not affect subjective or objective measures of cognitive workload
4. There is no relationship between stereo acuity and any change in cognitive workload experienced (in any condition)
5. There is no difference between measured stereo acuity in the different stereo tests

Next generation binocular HMD-JSF

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Methods

Apparatus

- Flight simulation: 270° field of view ‘out the window’ 4K screens & binocular SA-62 HMD (SA Photonics, CA, USA)
- Flight environment rendered by Diamond Visionics Image Generator. HUD symbology developed within ‘Unity’ game engine.

Wide field of view flight simulation displays and SA Photonics 62/S HMD

Photographs taken by OBVA personnel

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Investigate human performance using a stereo 3D HMD

- Full presentation with all data, conclusions and recommendations will be at AsMA this May in Reno by Sqd Ldr Posselt, RAF from PhD work completed in the USAF OBVA lab

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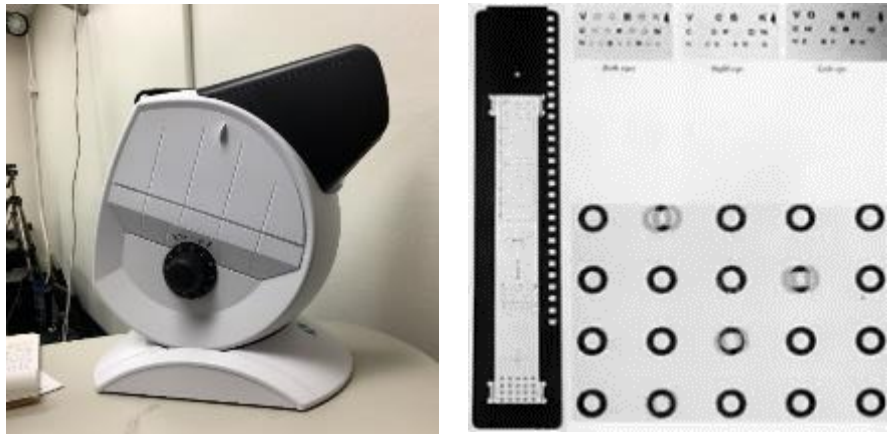
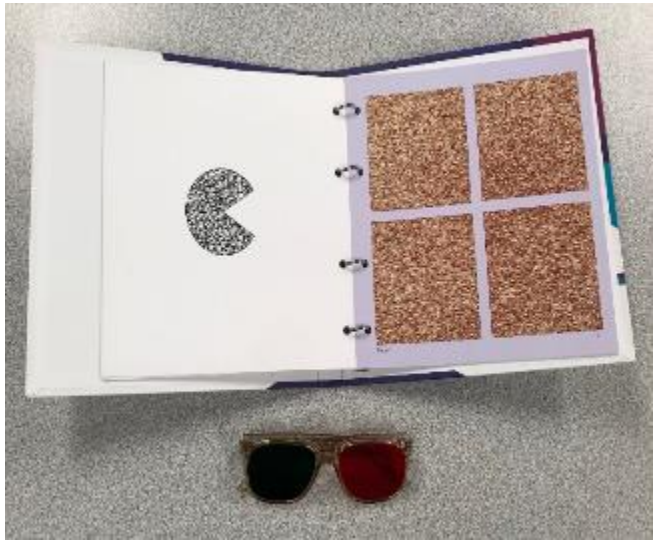
Recent HMD Research (cont.)

- Leverage DHP-funded AVT SBIR to develop new digital Random Dot Stereogram (dRDS) test
- Compare with current paper based tests for aircrew selection standards:
  - TNO test used by UK RAF/RN/Army
  - Armed Forces Vision Tester (AFVT) used by USAF



Armed Forces Vision Tester with stereo test plates



TNO test

Stereo search test – part of OBVA Automated Vision Tester

dRDS set up with TNO

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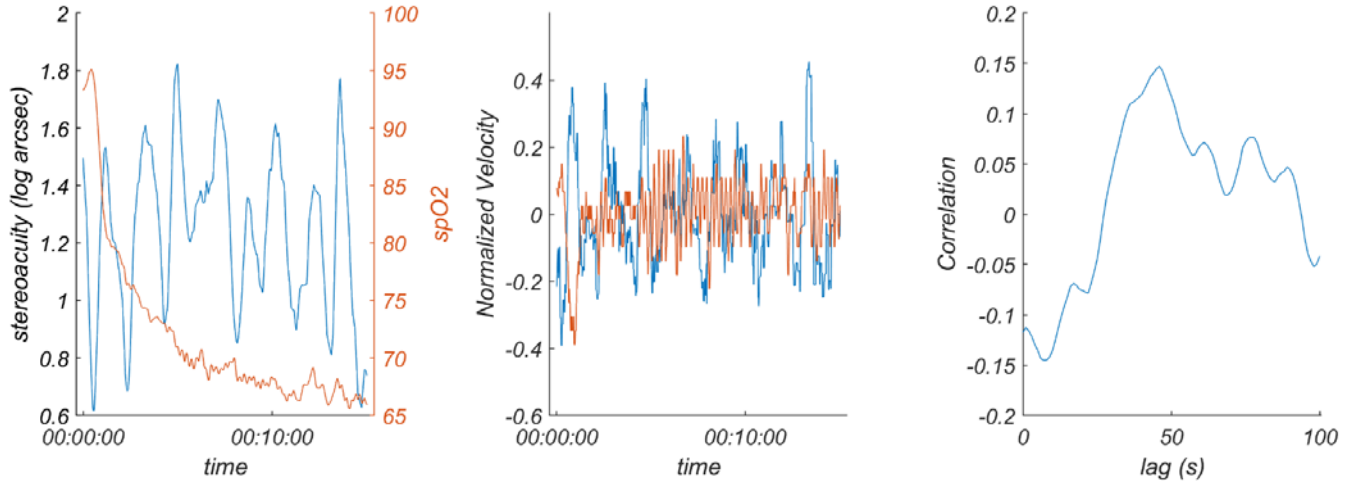
JPC-5 HMD Research (cont.)

- Teamed with NAMRU-D to examine effect of hypoxia on binocular vision (stereo acuity)
- Stereo tests under reduced oxygen conditions to simulated a hypoxic environment (20,000 ft)
- Preliminary results: SPO_2 appears to be directly related to stereo acuity
  - Improved stereo acuity about 20 seconds after spike in spO_2. Conversely, about 20 seconds after a dip in spO_2, degraded stereo acuity



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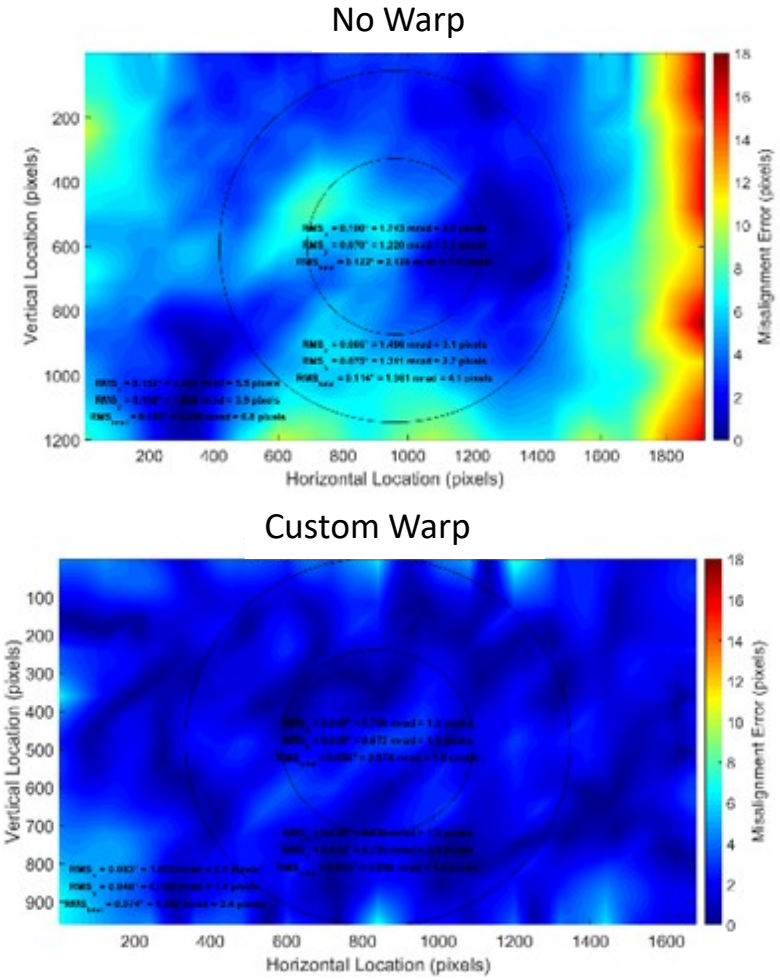
Future Research

- Develop methods to measure more complex binocular misalignment/image distortion[6]
- Characterize alignment/image distortion in fielded/commercially available HMDs
- Research effect of representative misalignment under conditions representative of real world operating conditions
- Research individual variability in tolerance to binocular HMD misalignment



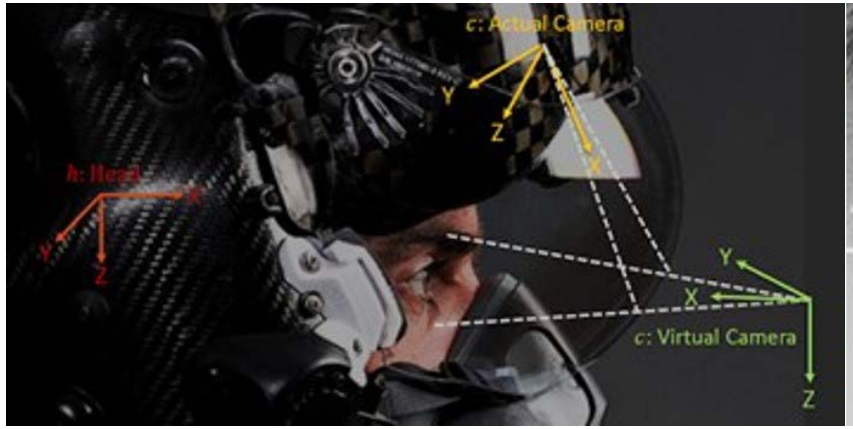
Relative right to left image misalignment with no image warping applied (top), and with custom image warp (bottom). Measurement obtained using optical alignment metrics developed by OBVA Lab for a commercially available binocular HMD.

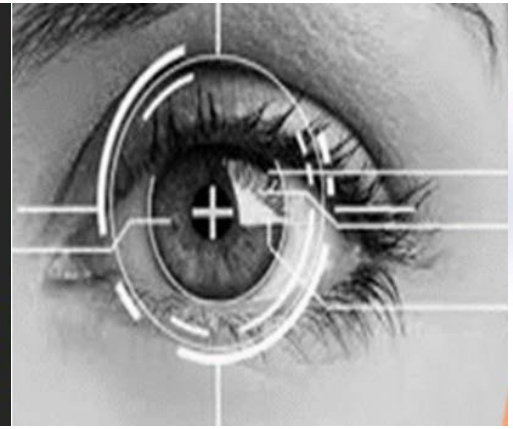
[6] Bauer, M., Williams, L., Nehmetallah, G., Van Atta, A., Gaska, J., Winterbottom, M., & Hadley, S. (2017, May). HMD distortion characterization and alignment toolset for precision-critical applications. In Degraded Environments: Sensing, Processing, and Display 2017 (Vol. 10197, p. 101970S). International Society for Optics and Photonics.

Current and Future HMD research

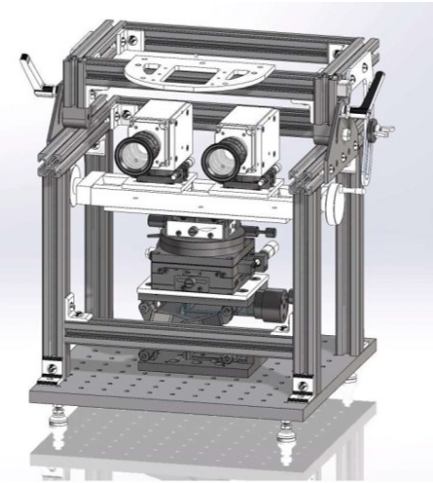
- Alignment measurements of fielded F-35 HMD, in partnership with SA Photonics
- Effect of sensor imagery misalignment on human performance, applicability of medical vision standards
  - Night Vision Camera (NVC) or Distributed Aperture System (DAS)
- Use of eye-tracking, other physiological metrics to evaluate human performance with HMDs
- Utility of color and effect of color deficiency in HMD/AR applications
- Investigating further effects of aviation operating environment – Hypoxia/fatigue

Virtual image – Distributed Aperture System (DAS)





Embedded eye-tracking concept



HMD alignment jig design

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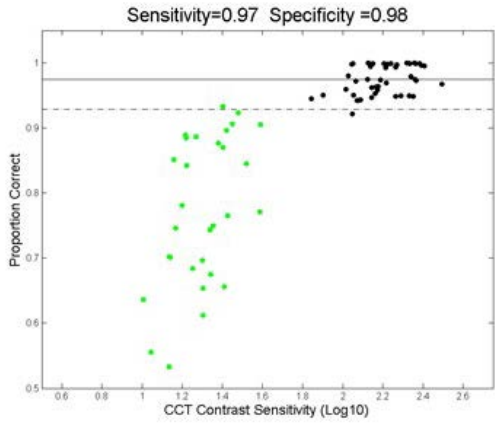
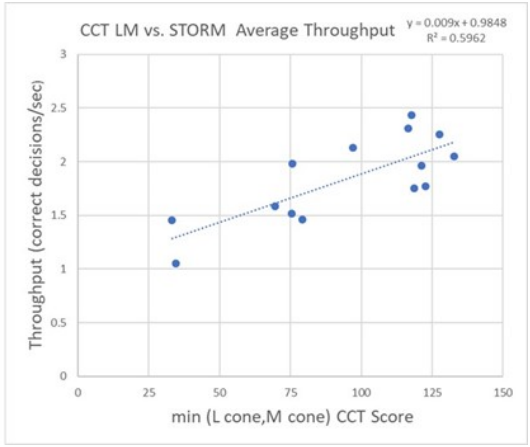
Future research

- Project Agreement with Australia's Defence Science & Technology Group (DSTG)
  - Five year collaboration research impact of HMD and VED design characteristics on human performance and relevance of aeromedical vision standards
- Finalizing DEA with Denmark – collect vision data for RDAF and USAF F-35 pilots at Luke AFB; collect questionnaire data from pilots regarding HMD experience
- Team with NAMRU-D – customized color palette for color deficient pilots
- *Team with US Army Aeromedical Research Laboratory – HMD technology for Future Vertical Lift?*





Effect of color deficiency on color coded display performance. Effect of low contrast symbology for 5th gen fighter cockpit MFD (left). RPA operator color display performance (right).

Gaska, J., Wright, S., Winterbottom, M., and Hadley, S. (2015). Operational Based Visual Assessment Using a Simulated MFD with Fifth-Generation Symbology. Presentation at the Aerospace Medical Association Annual Meeting, Orlando, FL.

Gaska, J., Winterbottom, M., Fu, J., Eisenhauer, G., and Hadley, S. (2019). Operational Based Vision Assessment: Color Deficiency and Performance on Simulated Remotely Piloted Aircraft Color-Coded Display Tasks. Presentation at the Aerospace Medical Association Annual Meeting, Las Vegas, NV.

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Questions?

Future NATO vision working group?