



# HUMAN MACHINE INTERFACES (HMI) CRITICAL TECHNOLOGY AREA (CTA)

## Vision, Strategy & Roadmap

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This presentation and accompanying HMI CTA Vision and Strategy Document can be found at:  
<https://www.dodtechipedia.mil/dodwiki/display/CTACS/Human-Machine+Interfaces>

JAN 2025

[HTTPS://WWW.CTO.MIL](https://www.cto.mil)  @OUSDRE



# HMI CTA BACKGROUND

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This document initiates the DoD road mapping efforts for the Human-Machine Interfaces CTA.

**2021 NDAA Sec 217** charges the Principal Director for each Critical Technology Area (CTA) with:  
*(b)(1) developing and continuously updating research and technology development roadmaps, funding strategies, and technology transition strategies to ensure--*  
*(A) the effective and efficient development of new capabilities in the area; and*  
*(B) the operational use of appropriate technologies;*

The “**USD(R&E) Technology Vision for an Era of Competition,**” signed by HON Shyu on February 1, 2022, describes the scope of HMI as:

Human-Machine Interface refers to technologies related to **human-machine teaming** and **augmented and virtual reality**. Rapid advancements in this technology area will have a multitude of benefits for our service members. Highly **immersive realistic training** environments provide real-time feedback to enhance Warfighter performance. **Intuitive interactive human-machine interfaces** enable **rapid mission planning and mission command** by providing a **common operational picture** to geographically distributed operations.



# HMI CHALLENGE

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MDO OV-1



**To accelerate decision-making, the Joint Force must discover and access any and all data from all warfighting domains, at all levels of Warfare.**

-- JADC2 Strategy

Volume of Data/Information



**Decision Making**  
(Speed-Accuracy)



Complicated Control (s)



Autonomous Systems, Swarm

Pilot Visual Interface (PVI) Controls

Meaningful C2 of AI Systems

CJADC2 Kill Web Integrated Actions

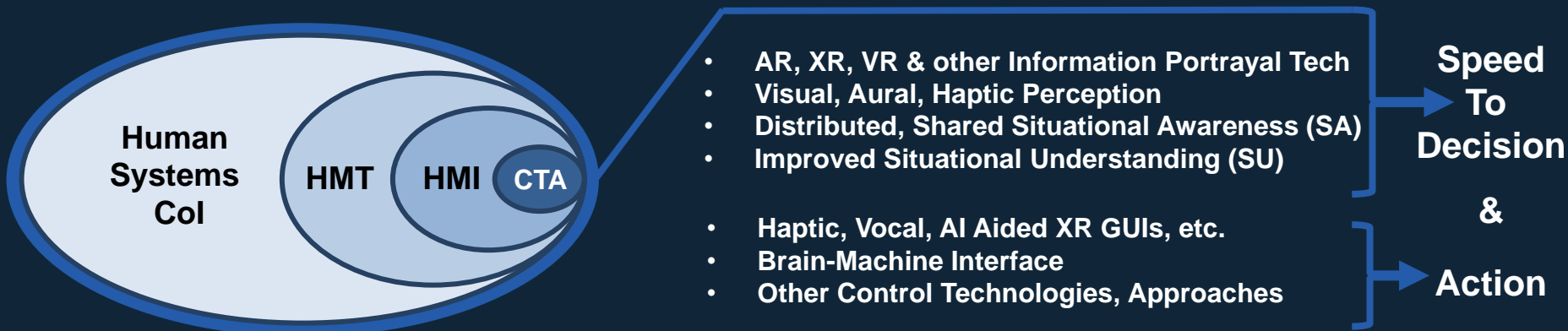
ATAK Manual Control

**Decision - Action Dominance can't be achieved without deliberate HMI efforts. HMIs are the bridge between "Data and Information Dominance" and the ability to realize Decision/Action Dominance.**



# HMI CTA SCOPING

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## CTA Prioritization:

- The HMI CTA cannot encompass all Human-Machine Teaming or HMI space, it is too broad
- Warfighters will be “In” and “On” The Loop for the foreseeable future for C2 of many systems
- Must align with priority use cases, NDS Strategy and Joint Warfighting Concept 2040
- Synchronize and prioritize Applied Human Sciences work, in operational contexts, with industry technology “far left of PMs”
- Acceleration Opportunities and Long-Term Investments to improve Decision-Action Dominance

**While other HMIs remain important, they are not the focus of the CTA.**



# ROADMAP FOCUS AREAS

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## FOCUS AREAS

## END STATES

### Information Portrayal Technologies

- Augmented, mixed and virtual reality technology optimization
- Visual, aural and haptic technology development & delivery
- Micro-Display component investment (with ME CTA, CHIPS ACT, Partners)
- US industry base growth & protection (MANTECH, Office of Strategic Capitol)

ID and drive critical paths  
Modified-COTs Exploitation  
Enable tech development  
Assess US Supply Chain

### Simplified Control Technologies

- Haptic/gesture, vocal, visual and other technology development
- Simplify complex GUIs, Common Control Architectures, UAS/Swarm Control
- Non-invasive Brain-Machine Interfaces (BMIs), Sensory Substitution Tech
- Leverage and Collaborate with Humans with Disabilities Accessibility Ecosystem

ID and drive critical paths  
Expand tech base/variety  
Integrate into DoD systems  
Incentivize Industry Base

### Applied Human Science: Embodied - Embedded

- Decision Making; Attention, perception, cognition of information ingestion
- Simplified Control (vocal, haptic, BMIs, sensory substitution etc.)
- Immersive DevSecOps environments to iterate Tech-Human Intx prior to field
- Immersive Training and Adaptable Learning Technology Optimization

Develop Best Practices  
Faster Decision/Action  
Simplified control  
Individual differences

### Ecosystem, Workforce & Infrastructure Efforts

- Industry – Academia/Lab (“Acadustrial”) collaborations “far left” of PMs
- Best practices repository, trade-space analysis, and context driven scenarios
- Applied Research Consortium (ARC) & Regional Centers of Excellence (CoEs)
- Early Investment & Collaboration (Users, Services, Academia, Industry, FVEY)

Develop and Unite Ecosystem  
Enable Collaborative  
Experimentation  
Integrate Best Practices for  
Operational Use



# MISSION PRIORITIES

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- **Tactical Data to Decision/Action (D2DA)**

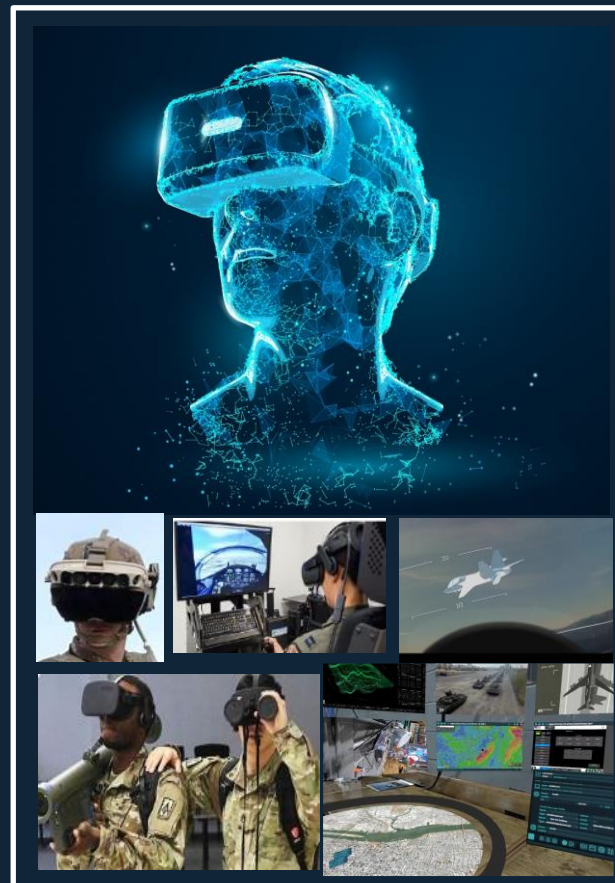
- Enhanced, Distributed and Shared Situational Awareness / Understanding
- Maintain the balance between XR/AR & Tactical / Real-World SA
- Accelerate/Integrate Simplified Control Tech (RAS C2, Pilot PVLs, etc.)
- Enable Cross Echelon, Joint Domain Awareness / Action / Outcomes
- Real-World Visualization of non-Visible Threats (UAS, EW, Cyber, etc.)

- **Mission planning and Command & Control (C2) in distributed, immersive environments**

- Improved distributed situational understanding, context-specific visualization, individual optimization
- Dynamic joint decision making → Rapid Re-Plan → Action
- Role, Echelon, Context and Security specific views (across CJADC2)

- **Immersive, realistic, joint Operational training**

- “25 Bloodless Battles”, Cross-Domain Joint Mission Training
- Improved, Accelerated and Greater Access for Platform Training (e.g. Submarine Bridge Trainers)
- Improved variety, complexity and specificity of training and threat scenarios
- Prioritized Joint Scenarios, ‘learning to learn’ jointly beyond JRX



**Its not enough to describe the Focus Areas for the HMI CTA. Mission Priorities must intersect these Focus Areas. The Strategy Emerges from their Intersection to initiate deliberate actions.**



# BUILDING THE HMI CTA (2024)

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**JAN-FEB 2024**  
Initial Scope/Focus (101)

## FEB-NOV 2024 STAKEHOLDER ENGAGEMENTS

INDUSTRY: XR/AR/VR, SIMPLIFIED CONTROL HUMAN SYS (95+)

USER COMMUNITIES, USG Labs, PEOs/PMs (70+)

OTHER GOVERNMENT AGENCIES (IC, NGA, NASA, VA, DHS, DoE, etc.)

FOREIGN PARTNERS (FVEY, NATO, NDL/TNO, NATO DIANA, JAPAN, ITALY, AUSTRALIA, etc.)

ACADEMIA (20+)

**Gaps, Priorities, Efforts**

NIWC-PAC HMI WORKSHOP

CJADC2 S&T WORKSHOP

DISMOUNTED WORKSHOP

LVC-IMMERSIVE WORKSHOP

AFRL WORKSHOP/PREP

VIRTUAL MINI-WORKSHOPS

**OCT/NOV  
2024**

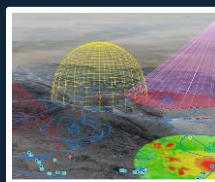
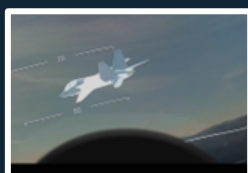
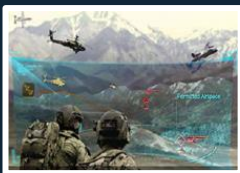
**ANALYSIS  
REFINEMENT**

**DEC  
2024  
FINALIZE**



# HMI CTA STRATEGIC VISION & APPROACH

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***Enable Decision-Action dominance by accelerating advanced technologies that optimize distributed human decision making, simplify control of complex systems and accelerate joint, immersive realistic training across Services.***

## Near

- Establish CTA & Key Ecosystem Partners
- Identify and Accelerate Early Opportunities to Field
- Leverage DIU, RDER, APFIT, and other acceleration mechanisms
- Increase investment in Technology and Supporting Human Sciences
- Influence DARPA Hard Futures
- Assess Display Technology & Industry Base Shortfalls

## Mid

- Realize CTA Ecosystem and Centers of Excellence (CoEs)
- Increased Human Sciences that Optimize HMI Technologies
- Deliver Common Control Architectures for Simplified Control
- Realize Distributed, Shared Tactical SA using XR/AR/VR Systems
- Expand Shared MDO Mission Command, Cross Echelon

## Far

- Deliver Multi-modal XR, AR, VR Systems Across Perceptual Systems
- Multiple, Adaptable Control Approaches for Operational Outcomes
- Deliver "Edge" to JOC Shared SA/SU Across Domain, Service, Echelon
- Deliver Advanced, Low SWAP-C Optical Display Technologies
- Bidirectional Brain-Machine Interfaces

**Optimized Decision / Action Dominance through Focused HMI Investments and Mission Priorities**



# HMI STATE OF THE UNION

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## HMI CTA TECH AND HUMAN SCIENCES EXECUTED “IN THE MARGINS”, UNPRIORITIZED

***“HSI is not prioritized or funded by the USG, and this can’t be on Industry to fix.”***

*-- Industry Quote, Non-attributable*

- Very low investment in the Human Sciences to optimize XR/AR and Simplified Control technologies.
- DoD problem sets will not magically emerge from industry, Modified COTs (M-COTS) investment strategy needed to bridge early and late-stage development and transition.
- Much focus on Autonomous Robotics, much less (near zero) on how they will be controlled in real world environments, in the middle of operational complexities by non-manual, > 1:1 means.
- Immersive LVC utility of XR/VR/AR systems mostly unrealized, though early efforts are demonstrating the value of extending access, training fidelity and cost savings.
  - Policy barriers and conservative assessments to distributed use must be addressed.

**HMI Requirements are ‘buried’ in Additional System Attributes (ASA), unarticulated (T/O) and Waivable/Tradeable in PMOs → not incentivized for S&T, PMs or Industry.**

**A lack of Human Systems prioritization, and HMI Technologies specifically, is an endemic issue for the DoD. HMI KPPs, *for critical systems*, must be institutionalized to prioritize/incentivize delivery.**



# STAKEHOLDER GAPS ANALYSIS



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## Cross Service Gaps

### TACTICAL D2DA

- Non-Manual, AI-enabled Simplified Control Technologies
- Common Control Architectures to expedite Simplified Control adoption
- DoD unique display maturity for XR/AR (especially for Dismounts)
- Aural, haptic and multi-modal information portrayal approaches
- Multi-domain threat visualization (RF, EW, Tactical SA)
- Human Sciences to Optimize and Inform XR/AR and Simplified Control

### MISSION COMMAND

- Intra- Service and Domain real-time COPs for dynamic mission planning and execution
- AI-enabled Decision-making tools for immersive, shared, distributed SA/SU with role/rank/echelon specific views
- Real-time COP data in A2AD / DDIL environments
- Autonomy C2 as integrated HMI / TAI&A Challenge (Meaningful Human Control)
- Human Sciences of task-performance & Cognitive Load and Fatigue in Situ

### IMMERSIVE LVC TNG

- Interoperable Immersive LVC Cross Service and Echelon Task Organization Training (MDO Training)
- Robotics / Autonomy LVC Replicates
- Agreement on degree of Fidelity required to conduct platform training, joint training and joint learning
- ATO, Wireless and Multi-level Security Challenge & Common Approach
- "Illusion of Life" for immersive LVC
- Task-Human-Machine Dynamics for Adaptive Training in Human Sciences

## Service Examples

- USA: Human-Machine Integrated Formation, simplified robotics control
- Joint: Fixed Wing PVI challenges and CCA "heads up" control approaches
- All: Common Control Architectures for Autonomous platform control (single and multi-agent)
- Army/USMC: Dismounted XR and Digital Night Vision Integrated Systems
- All: C-UAS XR Visualization
- All: Real world visualization of non-visual threats
- Shared Human Systems Focus, Ecosystem and Experimentation Infrastructure

- USA: XR Enabled On-the-move Mobile Command Post Distributed SA/SU
- All: Space, Strategic C3, and Hypersonic Predictive Visualization to aid SA/SU and rapid decision-action timelines
- All: Cross-Echelon Mission re/planning with AI-enabled automated CoA generation
- All: CJADC2 S&T Cross-Service Working Group Resourcing
- All: Unified Architectural Approach for Shared Information
- MDO Nested, Cross Echelon Group and Nested Individual Decision-Making Dynamics in Distributed Environments

- DIU: Pilot Training Transformation (PTT), Virtual Training for Air Dominance.
- SOCOM: Joint Fires Simulation Training Network
- All: JTAC VR / Immersive Training and Simulation Qualification
- USN: Sub / Surface VR- immersive bridge trainers
- USN: Next Gen Infantry Bn Trainer, Distributed Open-Ocean Mission Rehearsal
- DAF: Joint Simulation Environment (JSE) Pilot and Battle-Staff Training
- All: Human MOPs/MOEs Development, Task Outcome Optimization.



# HMI CTA ACCELERATION & INVESTMENT BALANCE

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**Lack of robust investment in the HMI CTA Focus Areas creates non-trivial challenges for Services to accelerate efforts and capability development/delivery in the near term.**

***Acceleration of Near-Term Requirements should be executed by those with responsibility and authority to deliver, not at the expense of S&T investments in Mid-Term Objectives.***

## NEAR TERM

## MID TERM

## FAR TERM

DIU, RDER, APFIT, PM EMD Priority

DoD S&T Investments to Accelerate & Invest to Realize Mid-Term

DARPA/Basic Research Investment

- Integrate, Demo & Deliver Simplified RAS Control (e.g. HMIF)
- Immersive LVC Training Systems (e.g. Submarine Bridge Trainer, Joint Fires Tng, Robotics Immersive Training.)
- “On the Move” XR/AR/VR Shared SA/SU (e.g. Army Mobile Command Centers)
- Pilot-Vehicle Interface & HMD gaps RELTO CCA et al.
- Context-Driven, XR/AR use cases, current technology (e.g. C-UAS)
- XR in VR Human Sciences Trades

### Investment Opportunities

- US Army IHSS (IVAS Next) S&T
- Distributed Shared SA/SU @ Echelon (e.g. JADPACT, Scalable Cross-Echelon C2)
- Human Fatigue, Task Dynamics in LVC Tng
- Human Sciences RELTO HMI Trade Space

### Mid-Term Focused Investment Gaps

- Immersive DEVSECOPS Environments
- Unified, Simplified Multi-Modal Control
- XR/AR Use Case Risk Reduction, AoA, Concept Dev
- HMI Autonomy Needs Analysis, Bi-Directional Human In and On the Loop – Meaningful Human Control

- Multi-Modal Control Systems, Sensory Substitution Technologies
- Bi-directional Brain-Machine Interfaces (BMIs) for SA and Control
- Persistent, Portable, Stable Neuro-Physiological Patterns of Task, Fatigue, Load IntX
- Human driven XR/AR Tech Optimization for low SWAP-C optical components
- Biologically Feasible, Multi-Scale Cascade Dynamic Models with Self-Emergent Dynamics for AI and BMI improved capabilities

**When Fielded, S&T deliberate spirals towards Objective (O) Requirements**

**Synchronized and Collaborative PM Transition Pathways**

**When Demo'd & De-Risked, S&T deliberate Ingestion for further development**



# HMI ECOSYSTEM AND INFRASTRUCTURE DEVELOPMENT

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## Applied Research Consortium (ARC)

- A Community of Action (CoA) that expands the existing Human Systems (HS) CoI with deliberate efforts aligned to the HMI CTA Technologies.
- Identifies Applied Academics, Partner Nations and Industry Scientists/Technicians in the XR/AR/VR and Simplified Control areas.
- ID, prioritize and expand existing efforts in the HMI CTA space by creating synergies and collaborative research, shared best practices, and the ability to conduct early experimentation with Warfighters and Industry.
- Work with Basic Research Office (BRO), Academics, and DARPA to derive early investment needs.
- Establish three sub-CoA's aligned with mission priority areas, aligned with Service Labs. Tactical, CJADC2 & Immersive LVC.
- Set cadence of conferences/meeting to organize, share outputs, provide networking, and grow/ ecosystem.

### TENANTS:

Minimal Governance Structure, Leverage Existing Communities and Synchronize, Add Complementary Approach to Drive HMI Priorities

## Experimentation Infrastructure

- Create HMI CTA related Experimentation Infrastructure
- Leverage, Expand, and Formalize Service Laboratory Leads
- Work w TRMC, Service Labs, User Communities to ID/Overcome Gaps
  - Conduct Iterative Testing and Demonstration w CoA
  - Users Determine Best Practices for Delivery
- Best Practices Repository with HFE / HSI Community
  - Experimentation "Far Left" of PMOs/PEOs

## Regional Centers of Excellence (CoEs)

Warfighters

Industry

Applied Science

2025 will focus on working with Stakeholders to establish the ARC/COEs & Alignment with Existing Capabilities (TAI&A, TRMC, etc).

## OUTCOMES →

- Unified HMI Ecosystem and Infrastructure
- Stakeholder Collaboration and Prioritization
- Early Industry/Science Interactions against Gaps
- Early to Late User-Validated HMI Outcomes
- Best Practices with Industry Involvement and Transition
- Regional Access, Aligned with Missions for Small Business



# HMI CTA ONGOING EFFORTS SECTION 217 REQUIREMENTS



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## Industry Base Assessment

- DCMA Industrial Management Division (IAD) will initiate an Industry Base Assessment in 1Q2025, with deliverables by 4Q2025.
- OASD (CT) OSI&A will support HMI CTA Software Industry Evaluations and Industry Conference horizon scans in specific advanced technology areas (e.g. Simplified Control).
- The HMI CTA will lead the AR, XR, VR Display Microelectronics and Microbolometers Industry Analysis for HMI, ME and IS&C CTAs across US & FVEY Nations for this critical component Gap to inform Strategy to leverage DoD, DoC and FVEY CHIPs investments.

## Workforce Assessment

- Specialty Engineering and Architectures (OASD, MC) conducts Workforce Assessments for Human Systems/Factors, Joint Service HSI Working Group (JWHSI WG), with the following findings:
- Workforce Adequacy Ongoing (2024-25)
- Standardized Competency Framework & Job Titles needed to Codify Practitioners
- Hiring / focus in Capability Development needed to promote sustainable professional growth, DAU competency

**Naval Postgraduate School (NPD) MS Program in HSI Halted, Why?**

## Intelligence Analysis

- Intelligence Community (IC) has been tasked with providing the HMI CTA with initial input via a Technical Intelligence Exchange Series (TIES).
- Initial TIES Feedback from the IC was provided in 4Q2024 and is reflected in the Gaps Analysis and Prioritization efforts for the current HMI CTA Roadmap.
- The HMI CTA TIES continues to refine questions for deeper understanding of Intelligence Analysis in emergent areas of need.

## Infrastructure Development

- Regional Centers of Excellence, aligned with Service Laboratories to incentivize accessibility for all Business – aligned with User Priorities / Applied Research Consortium (ARC).
- 2025 Actions include: location ID / Service Lab leads, Infrastructure Gaps Analysis, Where HMI CTA can leverage existing TRMC Capabilities, investments needed to complement HMI in existing ranges, minimal governance structure ROEs and additional Experimentation Area Requirements
- Resourcing against ID'd Gaps in 2026.

## Allied Engagements



- NATO HMT / HMI
- DIANA
- UK HMI
- AUKUS
- FVEY / NATO S&T
- ITALY

### Ongoing Assessments:

4Q24 – 3Q25: Cross NATO S&T HMI Landscape Synergies and Priorities

1Q - 3Q25: FVEY Display Technology Investment Landscape Analysis (Industry Base)

2025 EU/UK HMI Summit with ONR / ARO

- Potential NATO DIANA HMI Challenge 2025

## Key CTA Synergies

- Trusted AI & Autonomy (TAI&A)
  - RAS C2 "In/On the Loop Control"
  - AI Enabled Simplified Control from Physiological Signals / BMIs
  - JADC2 AI Enabled Decision Making COAs / Information Portrayal
- Microelectronics (ME)
  - Micro LEDs, OLEDs, low SWAP-C optics and Microbolometers for Digital Night Vision
- Integrated Sensing and Cyber (IS&C)
  - Microbolometers / Simplified Control



# HMI CTA 4 YEAR POAM

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