

# EXTENDED REALITY (XR) FOR MAINTENANCE AND REPAIR TRAINING

*Presented By: Joseph M. Friar and Olutoye Sekiteri*  
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Non-Lethal Weapons



RMQSI



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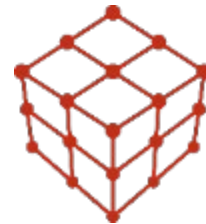
Weapons of Mass Destruction



Cybersecurity



Knowledge Management  
& Information Sharing



Modeling  
& Simulation



Software Data  
& Analysis

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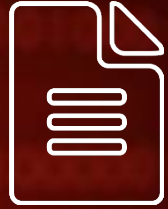
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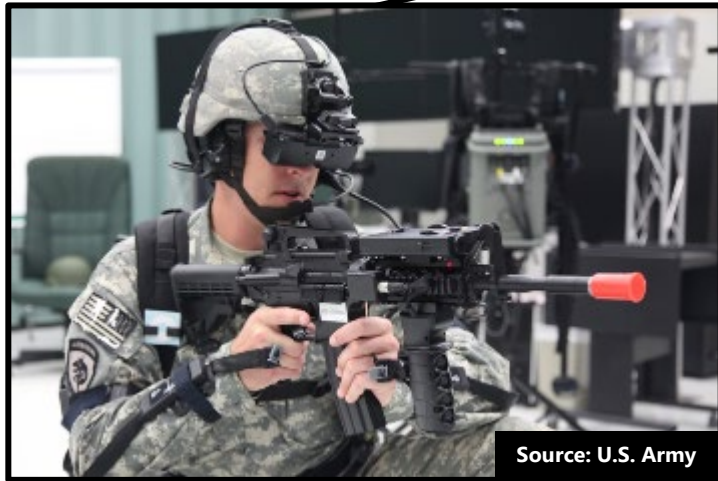
**EXTENDED REALITY FOR MAINTENANCE AND REPAIR TRAINING**

By Joseph M. Friar and Olutoye Sekiteri  
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Published By: CSIAc

  
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# What Is Extended Reality (XR)?

## Extended Reality (XR)



Virtual Reality (VR)



Augmented Reality (AR)



Mixed Reality (MR)



# Virtual Reality (VR)

- VR provides the user with a digital, simulated environment by using a headset or goggles that **completely obstruct the view of the physical world [1]**.
- An immersive experience in a digital space, VR is a computer-simulated experience in which computer technologies use reality headsets to generate realistic sensations and replicate a real environment or create an imaginary world.



Source: U.S. Air Force

# Augmented Reality (AR)

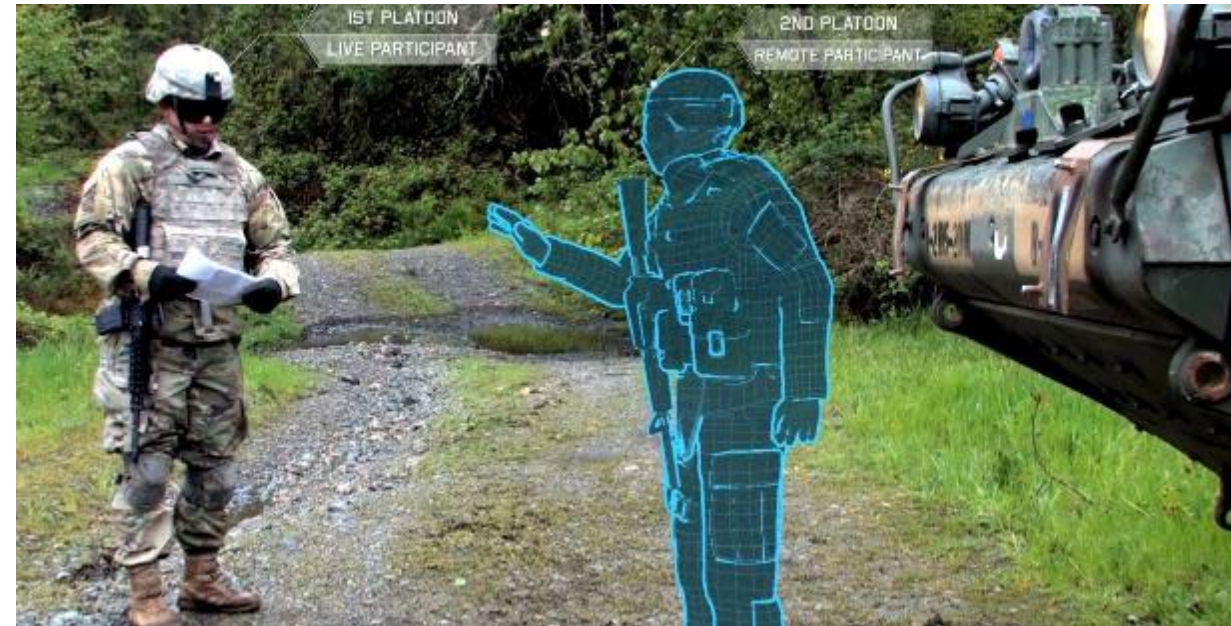
- AR provides users with an overlay of **digital information onto their view of the physical world.**
- The overlaid information can include images, texts, or 3-D models and is usually viewed through smart glasses, smartphones, or tablets.
- This allows AR to enhance the real world by adding virtual elements to the field of view without obscuring the physical world.



Source: Taqtile

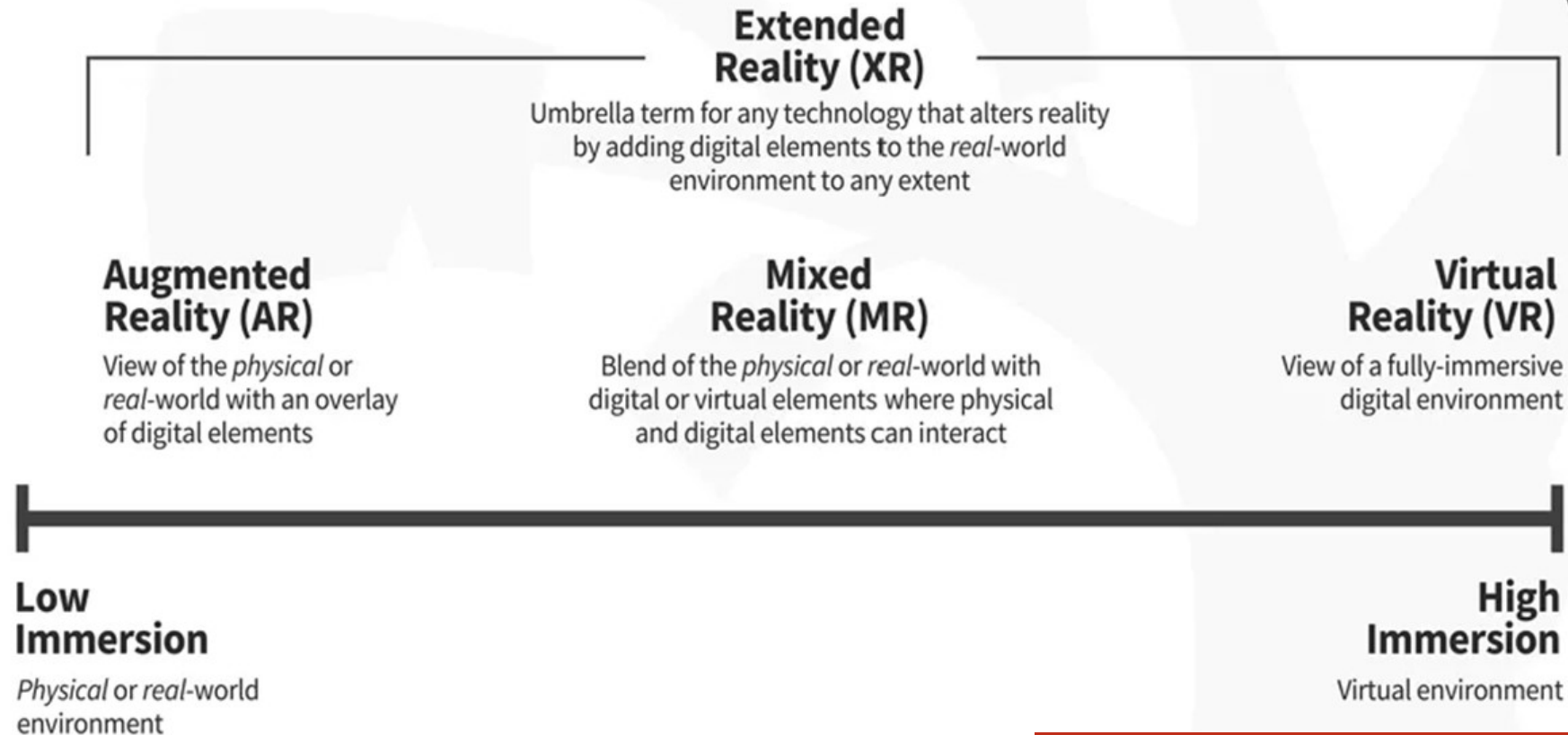
# Mixed Reality (MR)

- MR provides the user with an experience that combines both VR and AR. It projects **virtual objects onto the real world and allows users to interact with them.**
- Mixing both technologies creates a unique environment in which virtual and physical elements can be integrated into the same space.
- Sometimes called a hybrid reality, MR merges the real and virtual worlds to create new visualizations to interact in real time.



Source: U.S. Army

# XR in Spectrum of Immersion



Source: Interaction Design Foundation

# Case Study

- A prototype for a head-worn display was developed to assist military mechanics when performing maintenance tasks on armored vehicles [2]. To determine the effectiveness of the device, a study was conducted while mechanics from the U.S. Marine Corps worked on armored vehicle turrets using the headset.
- The display could assist the mechanics, as it guided them through complicated procedures by **providing visual elements like text, labels, and other indicators.**
- According to Henderson and Feine [2], those using the prototype could complete tasks more efficiently, and mechanics felt the technology was “intuitive and satisfying for the tested sequence of tasks.”



Source: U.S. Air National Guard

# XR in Maintenance and Repair

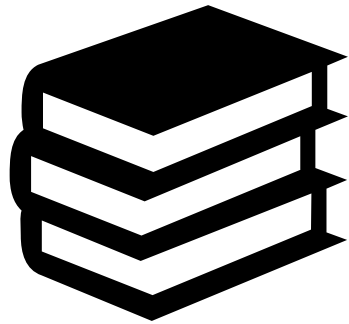
- **XR is an emerging technology** with many potential use cases for organizations across the U.S. Department of Defense (DoD).
- **XR is a transformative force** that can shape the way users perceive and interact with physical and digital elements.
- **XR software will become increasingly vital** in DoD operations, particularly in maintenance and repair training.



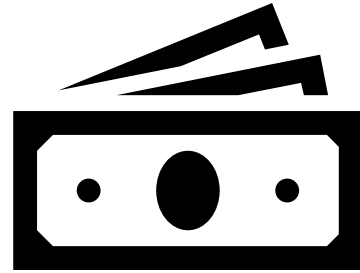
Source: Kimberly Conrad at Rock Island Arsenal-Joint Manufacturing and Technology Center

# Advantages in XR

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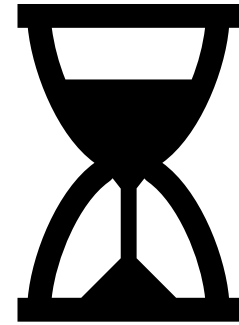
**Streamlined  
Education**



**Reduced  
Costs**



**Minimized  
Risks**



**Saved  
Time**

# Streamlined Education

XR technology is now used in classrooms and organizational training to **supplement traditional teaching methods [3]**. It provides these improvements by:

- Reducing the time spent in classroom training.
- Allowing students to train, even when physical equipment is unavailable.
- Enabling students to do preliminary training rehearsals prior to live training on physical assets.
- Preparing students to get the greatest possible value out of hands-on training opportunities.



Source: U.S. Air Force



# Streamlined Education (cont.)

- When XR was utilized in remote education, it was found that **trainees using VR could retain more information than trainees using educational videos [4]**.
- Researchers determined the effectiveness of the technology when applied to education by creating an aircraft maintenance simulator.
- The results showed that the group using the VR training scored significantly higher on a knowledge acquisition and retention testing 10 days later.
- Based on these studies, **users benefitted more from hands-on, instructed learning with XR** compared to traditional learning methods like PowerPoint slides or videos.



Source: U.S. Air Force

# Reduced Costs

- Training cost for qualified pilots [5]:
  - **F-16** - \$5.6 million
  - **F-22** - \$10.9 million
  - **B-1** - \$7.3 million
  - **B-52** – \$9.7 million
- XR technology used for training can **significantly reduce the cost** associated with planning and operating a training exercise.
- XR can eliminate the need for travel in certain training instances **and provides a platform for trainees, instructors, and others to collaborate seamlessly.**



Source: Taqtile

# Minimized Risks

- In a concept study, researchers found that **12% of serious aircraft accidents and 50% of engine-related flight delays and cancellations were caused by maintenance deficits [6]**. Complex routines of aircraft maintenance and repair not only increase costs but pose a risk to aircraft safety.
- **To help address this issue, an MR system was created to leverage digital aircraft components** and provide users with guidance during inspection processes. The inspector could also add marks to damaged sections of a component, which would be stored in the system's database and reflected on the part's digital version.
- XR technology could help address situations like these, as it provides solutions that can improve a technician's productivity, reduce operation errors, enhance the safety of maintenance/repair operations, and ensure overall compliance with industry-specific standards.



Source: U.S. Air Force

# Saved Time

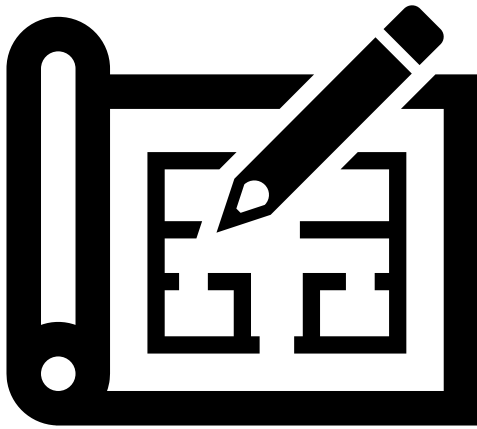
- **XR technology also reduces the time to complete various maintenance and training tasks.** Using real-time visuals like pictures, videos, and step-by-step instructions helps reduce the amount of time needed for completing tasks and troubleshooting.
- Boeing's aircraft from the 737 to the 787 have hundreds of miles of wiring that run through every new aircraft in different configurations. **Placement of these wires requires a high level of precision and accuracy, with little margin for error [7].**
- To reduce the cognitive load, Boeing has implemented Google Glass and Upskill Skylight to give their technicians the correct instructions without the need to look away at a laptop or smartphone. **Boeing claims that by implementing these technologies, they slashed production time by 25%.**



Source: U.S. Navy

# Challenges in XR

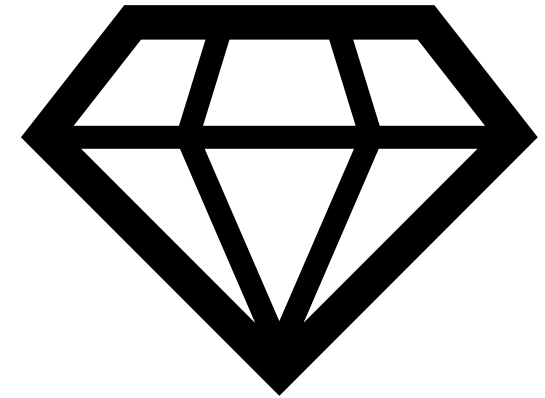
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**Design  
Obstacles**



**Health  
Effects**



**Price**

# Design Obstacles

- XR applications should only conveniently fill a user's field of view with necessary information, not overwhelm it.
- For these algorithms to be successful in detecting small details in a real-world view, highly effective, **image-processing algorithms need to be accurate and reliable, with little to no error [8]**.
- Uptime and connectivity can become a problem while collaborating with team members or asking for training or maintenance assistance.



Source: U.S. Air Force

# Design Obstacles (cont.)

- XR hardware can have many design obstacles, such as **graphics, depth perception, and portability [9]**.
- One of the main concerns with wearable displays is the **brightness and contrast** and providing a clear visual, regardless of outdoor lighting.
- Engineers had to ensure that the display did not emit too much light into the wearer's eyes to compete with external sunlight.
- **Interactivity with XR systems is also critical** - applications should have intuitive controls that users could efficiently learn.



Source: Russell Toof at U.S.  
Army Garrison Fort  
Leavenworth

# Health Effects

- One common challenge of XR technology is the strain on the body after wearing a headset for a prolonged period.
- Some health risks that may arise include, but are not limited to, **headaches, neck pain, eye strain, motion sickness, and fatigue [10]**.
- Developers have not yet perfected crafting heads-up displays for the user.



Source: U.S. Air Force



Source: U.S. Marine Corps

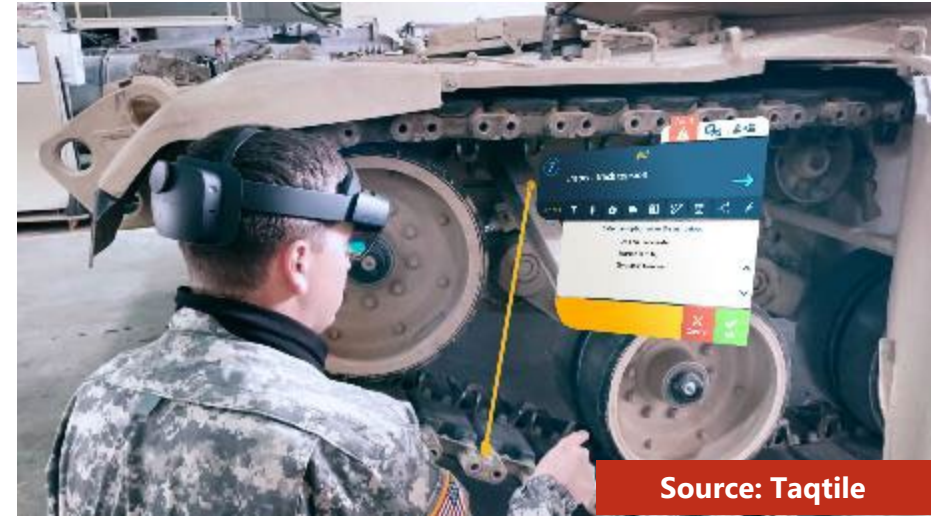


# Price

Company	Product	Category	Price	Release Date	Resolution	Refresh Rate
HTC	VIVE XR Elite	VR	\$1,099.00	March 2023	3840 × 1920	90 Hz
	VIVE Pro 2	VR	\$1,399.00	June 2021	4896 × 2448	120 Hz
Meta	Meta Quest Pro	VR	\$999.00	October 2022	3600 × 1920	90 Hz
Valve	Valve Index	VR	\$999.00	April 2019	2880 × 1600	144 Hz
Magic Leap	Magic Leap 2	AR	\$3,299.99	September 2022	2880 × 1760	—
Lenovo	ThinkReality A3	AR	\$1,499.99	November 2021	3840 × 1080	—
Vuzix	BLADE 2	AR	\$1,299.99	September 2022	960 × 480	—
Apple	Apple Vision Pro	MR	\$3,499.99	February 2024	7320 × 3200	90 Hz
Meta	Meta Quest 3	MR	\$649.99	October 2023	4128 × 2208	120 Hz
Microsoft	Holo Lens 2	MR	\$3,500.00	November 2019	2880 × 936	60 Hz

**Notable Commercial Off-the-Shelf XR Hardware, April 2024 (Source: Brown [11])**

# Impact Players For XR Maintenance



# Boeing's ATOM

- **Boeing has developed AR technology to facilitate rapid maintenance of deployed aircraft [12].** Named the Augmented Training Operations Maintenance (ATOM) technology, it was tested during the Mobility Guardian 2023 exercise conducted by the U.S. Air Force (USAF) Air Mobility Command.
- ATOM was used for remote support to assist engineers while they performed maintenance on a USAF C-17. The technology allowed an expert representative to provide holographic instructions over 800 miles away from the aircraft.
- Through AR-enabled guidance, voice commands, and hand gestures, the user benefitted from the technology during the maintenance session.



Courtesy of Boeing  
Defense Australia

# Defense Advanced Research Projects Agency's (DARPA's) PTG

- **DARPA has invested in solutions that combine AR and artificial intelligence (AI) to create “virtual partners” for military personnel [13].** Named Perceptually Enabled Task Guidance (PTG), the program allows an AI assistant to provide the user's field of view with critical data and instructions.
- For maintenance and repair, PTG would allow engineers to follow detailed instructions and visuals to accomplish complex tasks. The agency announced its funding opportunity in 2021 and has allocated \$40 million to create this AI-powered AR tool.
- Other notable technologies implemented in the project include deep learning, video analysis, and automated reasoning.



Source: U.S. Navy

# DiSTI's FMT

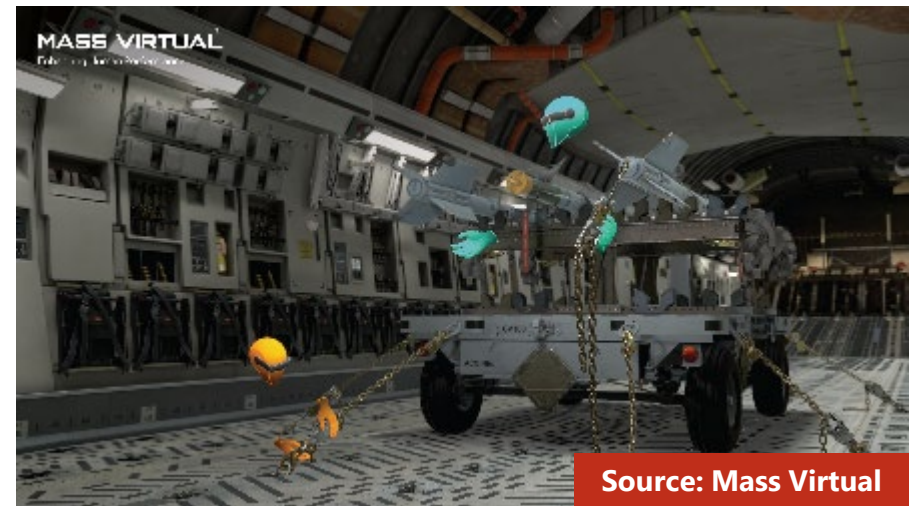
- **DiSTI provides XR software products for a variety of training scenarios**, including virtual maintenance training, virtual operations training, guided field services augmentation, and safety training [14].
- The company was awarded a contract in 2020 by the U.S. Army for the Family of Maintenance Trainers' (FMT's) Diagnostic Troubleshooting Trainers, which is being used to create virtual training to teach skills like fault diagnostics, troubleshooting, and repair.
- The contract was for indefinite delivery/indefinite quantity, with an initial ceiling of \$42.5 million.



Source: DiSTI

# Mass Virtual's Virtual Hangar

- **Mass Virtual has collaborated with the Air Force Special Operations Command** to establish new training frameworks that make use of XR technology [15].
- The Virtual Hangar is a training platform developed by the company to facilitate initial qualification training for all aircrew and mission support personnel.
- The platform supports VR training for the AC-130J, MC-130J, and CV-22, allowing munition maintenance crews to train using a variety of tools and learning modules.
- Mass Virtual has also developed other virtual training experiences, including a C-17 loading bay simulator and an explorable full-scale model of the C-5M aircraft.





**Committed to the Mission**

# Raytheon's VirtualWorx

- **VirtualWorx is an AR tool developed by Raytheon for defense training and simulation [16].**
- The focal use case for this effort is remote communication using AR, which connects users with experts to facilitate remote maintenance, technical assistance, and inspection and supplier support.
- VirtualWorx has created an effective solution as a remote communication tool and has become a favorable platform for end-to-end AR collaboration “to support the maintenance of aerospace and defense repairable assets” [16].
- The technology streams live video and audio between engineers, subject matter experts, and other parties involved in the operation, using virtual private networking to exchange secure information remotely.



Source: U.S. Air Force



# Taqtile's Manifest

- **Manifest is a software solution developed by Taqtile**, which “improves operational workflows so that jobs get done more accurately and consistently” [17].
- Field workers can use the software’s special computing capabilities to access maintenance data on any device. This allows customers to choose the hardware best suited for their needs, whether they prefer the hands-free solution that AR glasses provide or the accessibility of a tablet.
- The USAF implemented Taqtile’s AR solution to train jet engine mechanics. The Air Force Institute of Technology conducted a comprehensive study of the impact the Manifest AR platform had on routine technical orders (TOs). The TO information was converted into AR content on the Manifest platform, allowing visual instructions and steps to be displayed in the technician’s field of view.





**AUGMENTED REALITY  
WORK INSTRUCTIONS**

# Key Takeaways

- **Integrating XR technologies into maintenance and repair efforts across the DoD can have significant benefits.**
- The organizations discussed in this presentation have delivered solutions with profound results when deployed, whether using VR, AR, or MR technologies.
- XR-based training programs have significantly enhanced the way personnel consume training content and proved that interactive learning modules are usually more effective than traditional learning methods.
- The technology has the potential to transform legacy processes throughout the DoD and pave the way for an efficient and XR-enabled future.



Source: U.S. Army

**Questions?**

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