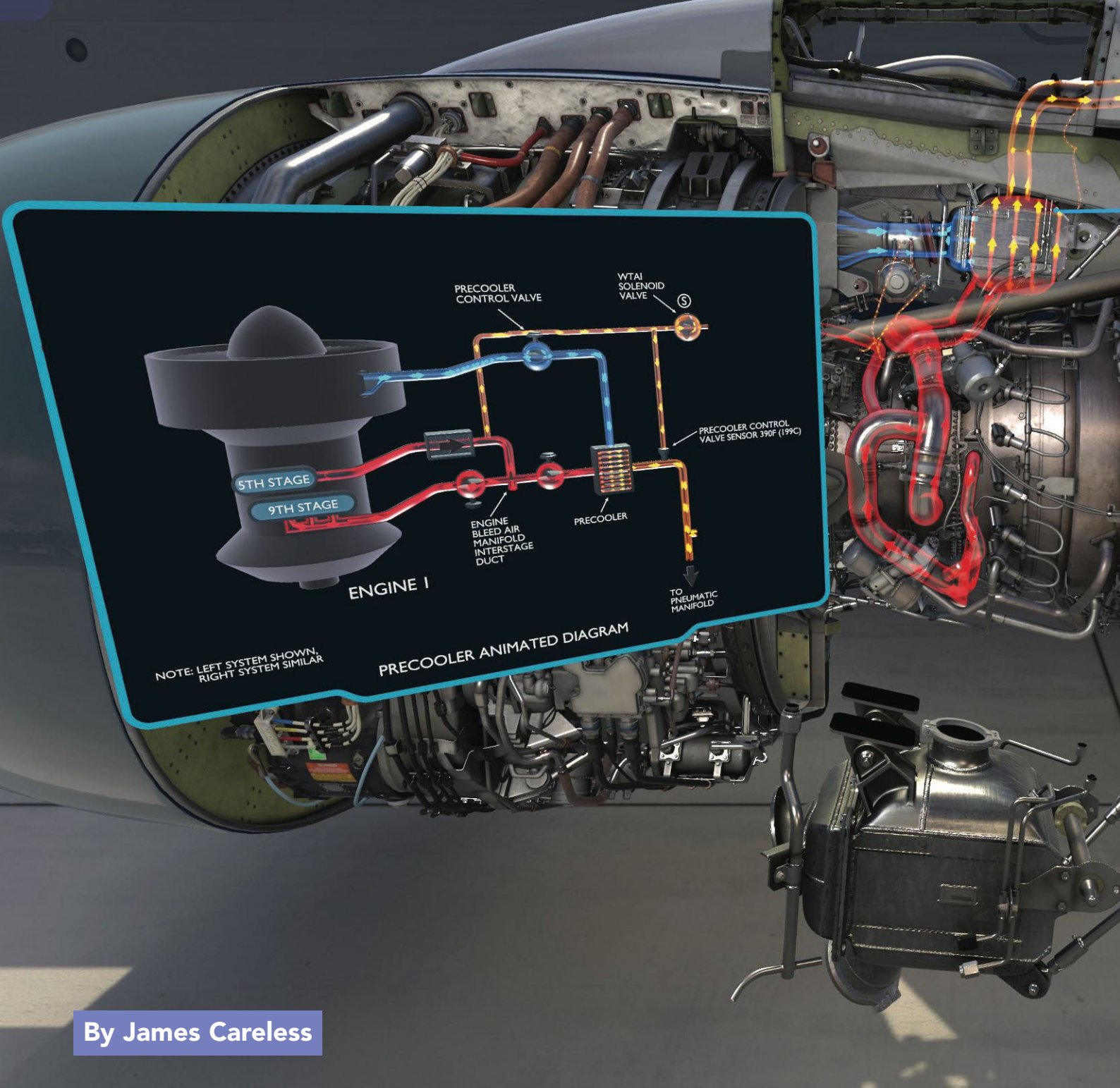




By James Careless

The Virtual Hangar: How XR Is Transforming Aviation Maintenance Training

Extended reality (XR) technologies — including augmented reality (AR), virtual reality (VR), and mixed reality (MR) — are transforming aviation maintenance training and support.

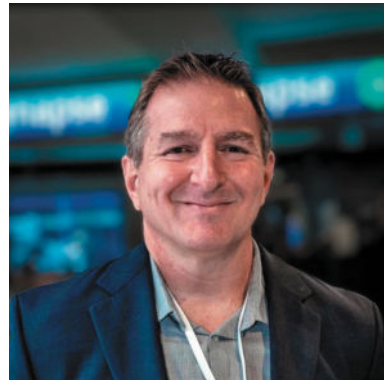
The availability of AR, VR, and XR

technologies is presenting MROs with unprecedented opportunities to enhance technician training, safety, and operational efficiency.

But how can MROs use these virtualization technologies effectively, applying methods that are safe, reliable, and trustworthy? To find out, Aviation Maintenance convened a virtual



David Dwyer



Dr. Phillip Mangos

roundtable of experts.

Our experts are David Dwyer, Mass Virtual COO. Mass Virtual develops immersive training technologies such as the MassXR platform, which is used by defense and commercial aviation applications. And Dr. Phillip Mangos, Adaptive Immersion CEO and founder. Adaptive Immersion develops VR training for dangerous work environments.

Aviation Maintenance: Please share a brief overview of your business, including how you are currently using AR, VR, or XR on the shop floor, the main benefits and drawbacks you see, and how you are addressing those issues.

Mangos: What got me interested in this space was my personal history developing personnel selection assessments for individuals in dangerous jobs. I realized that the best way to predict someone's performance on the job is to let them actually try out

the job itself. Back in the day, we didn't have the technology to offer that safely, especially for dangerous roles before someone was hired and properly trained. Now, with high-fidelity, immersive virtual reality technology, we can.

To this end, Adaptive Immersion develops adaptive VR and XR training for the world's most dangerous missions and occupations, focusing on military and industrial safety settings. We provide operators with unlimited, variable, realistic practice that classrooms and live drills simply can't provide before their first real attempt on the job.

Specifically, we provide training for aviation-adjacent operator roles — the personnel charged with keeping aircraft operational, safe, secure, and ready to fly. This includes teams specializing in maintenance on the aircraft itself, weapon systems, and explosive ordnance disposal (EOD) personnel.

An exemplar use case is our hands-on procedural VR training for personnel face to face with ordnance threats. The system provides

hyper-realistic visuals and precise task replication so operators can do everything they would do in the real world within a safe virtual environment.

The primary benefit is a large increase in practice repetitions and variability on an accurate replica of a real aircraft, which is crucial because live aircraft impose significant restrictions on availability. More practice across varied conditions improves skill development and permanence while enhancing safety in the vulnerable first 90 days on the job when operators are at the greatest risk of injury or incidents.

One drawback we see is general pushback to training in a headset, usually rooted in a lack of familiarity with the technology. However, when people see the visual quality and psychological fidelity of the task firsthand, backed by quantitative ROI data, that pushback tends to fade.

Dwyer: Mass Virtual develops immersive training and learning technologies that help organizations shift appropriate training into high-fidelity digital environments, creating more opportunities to practice, measure performance, and build capability while reducing unnecessary dependency on operational resources with the ultimate outcome of increasing organizational operational performance.

Our MassXR platform powers immersive training programs across defense and commercial aviation, including Virtual Hangar for the U.S. Air Force. The largest benefit we see here is increased access to training, the ability to safely practice low-

frequency/high-consequence tasks, and see true measurable technician performance.

The largest challenge with AR/VR/XR is that not every task belongs in this medium. We focus on applying the right solution to the right part of the learning or maintenance workflow, rather than trying to replace every existing piece of training or support material.

Aviation Maintenance: Which specific AR, VR, or XR hardware and software platforms are you actively using, and can you share concrete examples of how technicians use them during daily maintenance tasks?

Mangos: We use a standard hardware stack built on best-in-class equipment, primarily using the Varjo XR-4 series in pure-play VR mode with some mixed reality (MR) applications. We favor the tethered version for visual fidelity and security reasons, supported by GPU-powered desktop or laptop computers. Some setups require a base station for tracking, and we use peripherals like a floor mat and fan to help orient users in physical space, along with custom training aids, props, and standard controllers to ensure a smooth experience.

On the software side, our custom VR system embeds intelligent scenario generation and visual effects to deliver customized immersive training experiences.

In terms of real-world use cases, military operators across multiple bases use our solution for mission preparation and

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Adaptive Immersion uses a custom VR system that can embed intelligent scenario generation and visual effects to deliver customized immersive training experiences, Dr. Phillip Mangos says. Adaptive Immersion image.

curriculum-based practice on the exact aircraft they maintain during live operations. Think of an F1 racing pit crew rapidly servicing a car: when aircraft land on an aircraft carrier between sorties, teams must perform rapid maintenance on the airframe, weapons, and ordnance to prepare the aircraft for the next round. Our VR trains technicians for those high-pressure turnaround environments. If an aircraft returns with an ordnance-related hazard, we can train EOD and maintenance personnel in the procedures required to render it safe before maintenance proceeds.

Dwyer: We remain hardware agnostic, but have fielded solutions with numerous COTS hardware solutions including HTC VIVE Pro 2, HTC Focus Vision, Meta Quest 3, Microsoft HoloLens, Magic Leap 2, and most recently Samsung Galaxy XR. Since we are a solutions provider, our focus is less about the specific hardware choice, and more about improving operational effectiveness by preparing and assisting technicians before and while they are on the aircraft.

Our largest footprint of deployed solutions resides within the U.S. Air Force, where we have a large footprint of VR solutions and a smaller cadre of AR solutions deployed across nearly 300

global locations, covering over 35 different platforms, training over 31,000 users annually. This effort has been largely focused on reducing the dependency of training and familiarization on actual aircraft platforms, and preparing the maintainer to be ready when they first touch the aircraft.

A large focus has been placed on developing procedures and training solutions that address low-frequency, high-consequence tasks. By deploying these solutions, we have reduced aircraft downtime by about 45%, decreased classroom training hours by 60%, and increased task efficiency by 15%. In this instance, Mass Virtual's software platform, MassXR, provides the content, distribution, learning management, assessment, and reporting capabilities behind these solutions.

Aviation Maintenance: What specific operational advantages and improvements in efficiency, accuracy, or turnaround time have you seen from using these technologies on the floor?

Dwyer: Our solutions have been fielded to our customer base, and they have conducted independent studies of the effectiveness.



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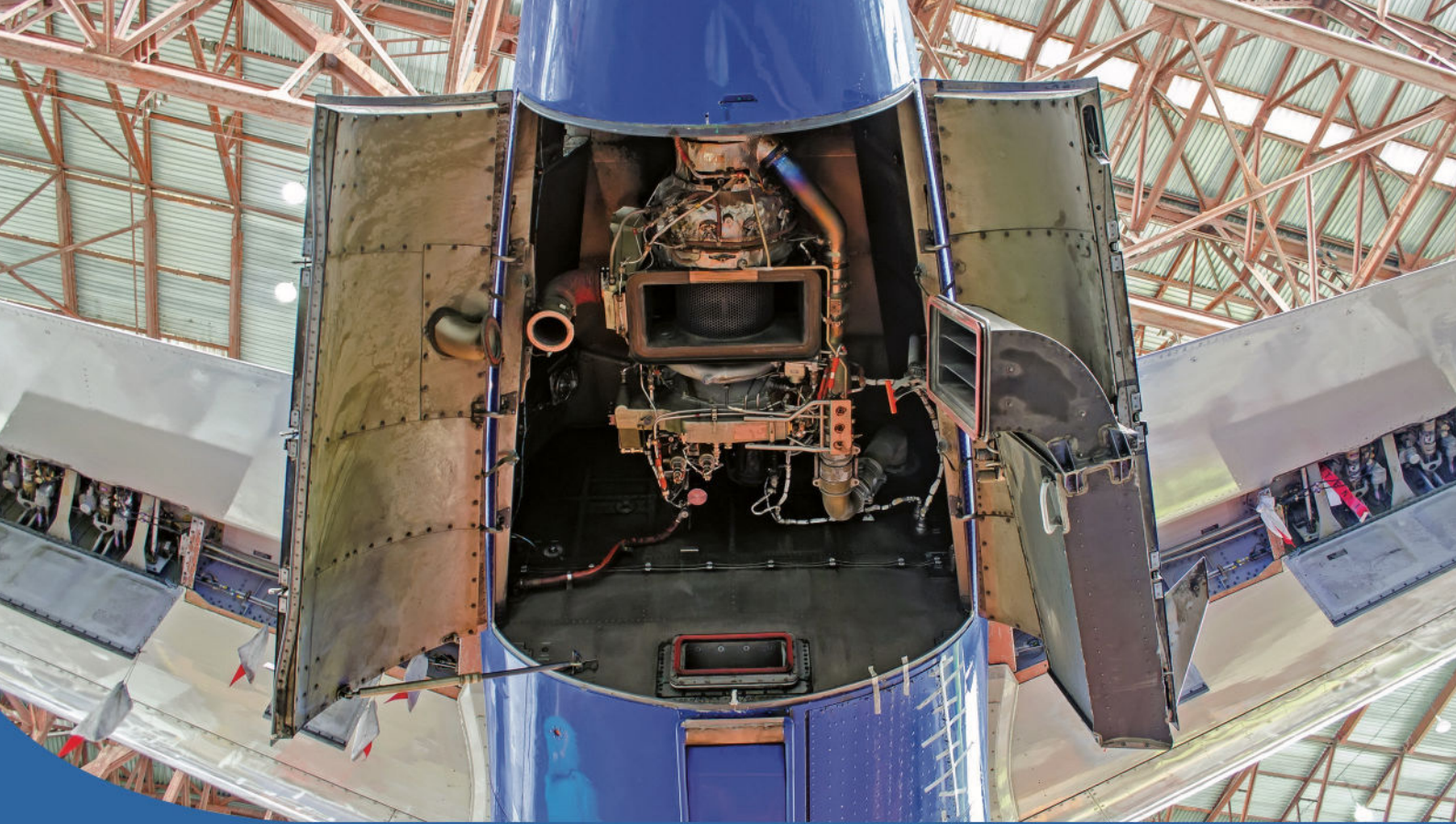
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"The most expensive classroom in aviation is a grounded aircraft," according to Adaptive Immersion's Dr. Phillip Mangos at a conference earlier this year. "Every hour of on-aircraft training competes with availability, and every experienced instructor is stretched across more students than the pipeline was built for. What we are showing on the most advanced XR hardware in the world...is a way to move the repetitions into the headset and keep the aircraft flying — without letting the procedure drift between the practice environment and the real one." Adaptive Immersion image.

One of the strongest advantages of XR is that it decouples training availability from aircraft availability. In a recent article, Little Rock Air Force Base cited an \$18.5M savings in mitigated training costs by enabling the ability to train and prepare without real aircraft using our Virtual Hangar (powered by MassXR) solutions. The 913th Airlift Group at Little Rock AFB has no aircraft assigned for this training, yet maintainers use multiple virtual aircraft platforms without needing physical flight line access.

In addition, the ability to become familiar with an airframe or procedure that you may not have experienced in the past, or one that is still in development, is where we are finding a real fit. In these instances, we provide crew coordination and maintenance training before the aircraft is even fielded or configured. The ability to train earlier in the pipeline is one of the most compelling uses of XR.

Mangos: On efficiency, we have documented significant increases in practice repetitions without operators touching a live asset, resulting in reduced reliance on limited live aircraft and classroom resources. Live training exercises are expensive, difficult to coordinate, and carry heavy logistics and personnel costs. Our VR acts as a high-fidelity supplement, allowing maintainers to get many more "reps and sets" safely.

This increased throughput directly impacts on-floor performance. In our training environments, operators show score improvements across 20 reported cognitive dimensions. All of this has been validated against real-world floor performance, demonstrating significant gains in efficiency and task accuracy, particularly for hard-to-practice maintenance procedures.

A prime example is our training for "broken arrow" scenarios — rare, high-consequence events involving crashed aircraft carrying nuclear weapons. Operators rarely get live practice for these events because training sites are so limited, but VR allows them to build readiness for these critical situations risk-free.

Aviation Maintenance: What are the biggest technical shortfalls or limitations of the current technology, and what features or capabilities still need to improve?

Dwyer: For VR, the majority of technical barriers have reduced as the technology has matured. However, the remaining gap for maintenance operations remains in the AR space.

A shortage of mission-capable AR headsets/glasses continues to be a challenge. In hangar and flight line operations, current AR hardware struggles with operating in diverse lighting conditions and battery power limitations. While these remain hurdles for true flight line execution, we continue to find great success utilizing full simulation prior to performing real-world tasks.

Mangos: One of the biggest technical shortfalls is equipment durability. Best-in-class hardware contains sensitive optical and electrical components vital for high immersion. However, maintaining "handle-with-care" hardware is a challenge for hands-on maintainers and ordnance professionals who work in rugged environments with heavy-duty tools and might toss equipment around in the course of their duties. There is a clear need to increase hardware durability for operational field use.

While visual fidelity continues to make great strides, the overarching challenge across all XR training comes down to psychological fidelity — accurately capturing the exact mental and cognitive processes used to solve problems in the real world within the simulated environment.

Psychological fidelity is not purely a hardware issue. You can have photorealistic visuals and high frame rates, but still fail to address the isolated task components most susceptible to skill decay. Building true psychological fidelity requires a strong skill assessment and measurement foundation, adaptive instructional features, and deeply probing after-action review (AAR) and debriefing capabilities.



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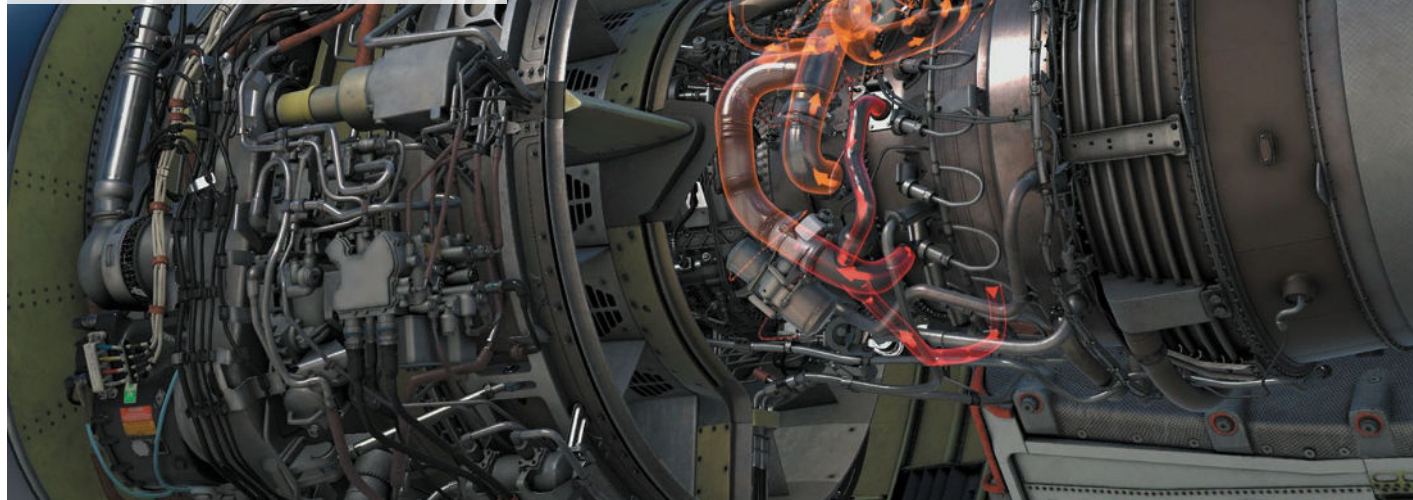
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Mass Virtual's David Dwyer says XR becomes particularly valuable when the maintainer needs to understand location, spatial awareness or interaction with a complex system or task. Reading or looking at a 2D wire diagram doesn't always give the best theory-of-operations understanding for how things work. XR fills that gap. Mass Virtual image.



Aviation Maintenance: What physical infrastructure upgrades, hardware investments, or IT changes were required to deploy these tools across your shop?

Mangos: No major physical infrastructure or IT upgrades were required. Our system is optimized to be highly compact and portable — requiring only a GPU-capable laptop or PC, tethered Varjo XR-4 headset, controllers, tracking base stations, a floor mat, and a fan. Outside of cybersecurity compliance considerations, all that is needed is a dedicated physical space with standard electrical power and climate control.

To ensure success, the focus needs to be on standardization and train-the-trainer programs so local instructors know how to install and run the system correctly.

Looking to the future, there is strong interest in moving toward wireless and cloud-based collaborative experiences, enabling operators at different geographic sites to train together in real time. Building infrastructure that supports remote, massively distributed collaboration without compromising visual or simulation fidelity will be an important evolution.

Aviation Maintenance: How have you handled reskilling and training your technicians, and how has the shop floor staff reacted to using these tools in their daily routines?

Mangos: We address reskilling through two layers. First is basic education — educating users on the benefits of VR and enforcing standard best practices to minimize disorientation or cybersickness. Second is standardization and train-the-trainer programs, ensuring local instructors can onboard users smoothly so technicians learn baseline control inputs quickly without fumbling.

When a training program is designed correctly around "psychological fidelity," transitioning to VR isn't a huge leap because it mirrors the cognitive and procedural demands of their actual job.

Because of this approach, end-user reactions have been overwhelmingly positive. We also maintain a direct user feedback loop to identify pain points and continuously improve system usability.

Dwyer: One lesson and theme we have seen over our deployments is that adoption of XR, when incorporated into existing training, has a significantly greater impact than deploying it as a standalone solution.

As evidenced in our Fort Bliss fielding, initial skepticism is easily removed when you present a high-fidelity solution that accurately replicates the real world. The technology has to solve a real problem for the maintainer. If it does not make the task more accessible, effective, or useful, simply putting a headset on will not drive adoption.

Aviation Maintenance: What are the overall pros and cons of using XR platforms in real-world MRO operations compared to traditional paper or tablet-based workflows?

Dwyer: We generally don't view XR as a replacement for every paper or tablet-based workflow. XR becomes particularly valuable when the maintainer needs to understand location, spatial awareness, or interaction with a complex system or task. Simply reading or looking at a 2D wire diagram doesn't always give the best theory-of-operations understanding for how things work. XR fills that gap.

Mangos: The main pro of immersive VR/XR is the ability to achieve high visual fidelity and rapid, accurate replication of dangerous, repetitive, or procedurally complex work in a safe environment without interrupting actual operational task flow. This full immersion drives direct, measurable skill development and clear training ROI.

The main cons are that not everyone is naturally suited for immersive VR. Some users are more prone to cybersickness,

imposing an upper time limit on headset usage before discomfort sets in.

Aviation Maintenance: Are there any lessons learned that you want to share?

Dwyer: There are two primary lessons we have learned from our deployments:

The experience has to be worth the effort: We must deliver a solution that gets beyond the friction of putting a physical device on. It has to bring efficiency or actionable information that helps technicians do their jobs better. You must see a clear operational gain to justify deploying XR.

Access is paramount: Aircraft are expensive, instructors are limited, and many maintenance procedures occur infrequently. XR provides a continuous training resource independent of physical aircraft availability. This shifts the economics of technical preparedness, allowing rehearsal to occur much earlier so that limited time spent on actual aircraft is vastly more productive.

Aviation Maintenance: What are your future plans for expanding or evolving your use of AR, VR, and XR technology over the next few years?

Dwyer: We are continuing to field VR, AR, and traditional solutions. As hardware matures, we expect the lines between these platforms to blur. VR will remain extremely effective for immersive training

and rehearsal, but the next generation of XR hardware — featuring improved hand tracking, pass-through capabilities, and smaller form factors — will bring a massive leap forward.

Over time, we expect the line between pre-task training and real-time performance support to dissolve. Advancements in hardware and AI will soon allow us to deliver contextual instructions, data, and remote expert assistance directly to the maintainer in their live work environment. Our focus remains on building a robust content and software ecosystem that evolves alongside the hardware.

Mangos: We plan to expand our XR technology into adjacent military and industrial domains involving dangerous, hands-on technical work — such as oil rigs, gas, energy, and mining.

We are expanding our software features to make the user experience both highly functional and visually seamless. A major focus is advancing our skill assessment and After-Action Review (AAR) framework, enabling maintainers to pinpoint exact procedural errors and rewind time to play back their specific actions leading up to a mistake.

Lastly, we are expanding our intelligent scenario generation capabilities, leveraging advanced artificial intelligence to create dynamically adaptive scenarios tailored to the operator's specific job requirements. **AM**



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