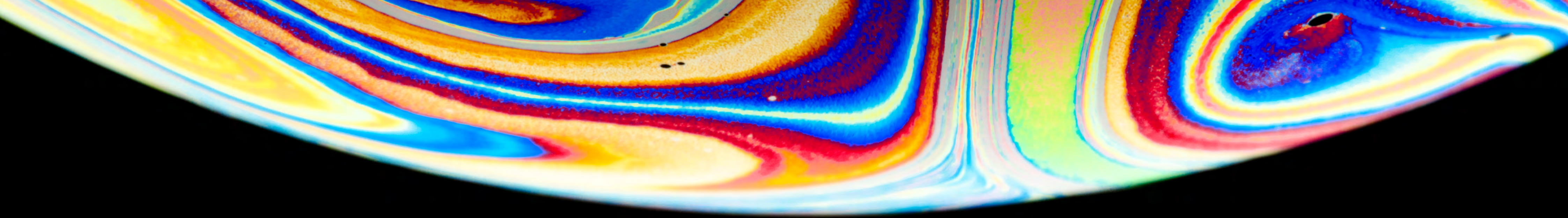

Mirroringreality

DIGITAL TWINS IN AEROSPACE AND DEFENSE

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Capgemini RESEARCH INSTITUTE

Introduction

Digital twin technology is not a novel concept for the aerospace and defense (A&D) industry; however, it is emerging as an increasingly important one. Simply put, a digital twin is a virtual replica of a physical system whose performance it can help optimize. Because it exists purely in the virtual space, the twin can be stress-tested, assessed, and its design modified with no safety implications and at optimum cost, so that all the experimentation and major decisions can be nailed before the physical asset itself is touched. Given the multitude of challenges faced by A&D, including supply-chain disruption, the imperative to lower the total cost of ownership (TCO), the skilled labor shortage, an aging workforce, safety and regulatory-compliance requirements, the need to

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reduce carbon footprint continually for a sustainable growth, the ability to address these questions virtually before committing to a phyiscal solution makes digital twin an invaluable tool to drive the industry towards its goals.

Digital twins use real-world operational data to run simulations and predict likely outcomes, meaning that all conclusions may be applied discreetly to the physical asset. Leveraging other technologies such as Artificial Intelligence(AI), the Internet of Things (IoT), and immersive technologies such as augmented reality (AR), virtual reality (VR), and mixed reality (MR) – digital twins bridge the gap between digital and physical worlds. They establish a closed-loop approach to synergizing data, technologies, and business processes. The results can be astonishing.

Today, large aerospace original equipment manufacturers (OEMs) are eagerly applying digital twins to various segments of their manufacturing processes. *"Our digital twin allows us to model, simulate, and scale a wide range of situations for critical stakeholders, including drone and aircraft pilots, operators, regulators, and the UTM [unmanned traffic management] service providers themselves,"* explains Max Egorov Nova, Airbus UTM's Head of Simulation.[1] In the defense industry, a digital twin enables the armed forces to play out a range of operational scenarios and enemy responses in a

Introduction

realistic but consequence-free 'wargame' structure, leaving troops better prepared in high-stakes battle situations.

The scope of digital twins is not, however, limited to terrestrial matters. US aerospace company Lockheed Martin is collaborating with software business NVIDIA on an artificial intelligence (AI)-driven Earth Observations Digital Twin, to help model potential developments in global environmental conditions, such as extreme weather events.[2]

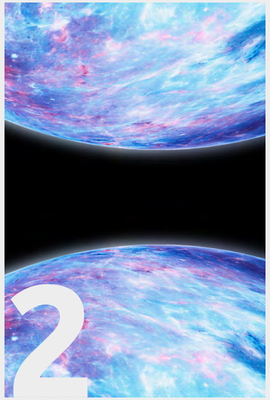
Airport operators are also making use of the technology. Vancouver Airport Authority has launched a digital twin of Vancouver International Airport (YVR). The platform allowed the airport's guest-experience team to anticipate and relieve passenger congestion at security checkpoints during the busy travel season in 2022.[3] YVR is also beginning to use digital twins to model aircraft movements and airfield activity, facilitating reduction in greenhouse-gas (GHG) emissions.[4]

In 2022, we launched a study to assess the benefits of digital twin across various industries (including A&D) and illustrate how the technology is at the core of Intelligent Industry[5] transformation. Our latest report takes a deep dive into the A&D industry examining digital twin use cases that are changing industry dynamics. Of the 150 A&D organizations that took part in this second survey, 80 percent have ongoing digital twin programs.

Introduction

This report, which is a part of our series on Intelligent Industry, comprises four parts:

How the A&D industry relies on digital twins for design and operational efficiencies



How digital twins can add value throughout the value chain

How digital twins form the backbone of the industrial metaverse

How the A&D industry can accelerate its digital twin transformation

Executive summary

The A&D industry is used to the pressures inherent in a complex ecosystem of supply chain partners that is subject to demanding regulatory and certification challenges. The pandemic caused additional, drastic disruption, however, hitting commercial aviation hardest. Eighteen months ago, our digital twin research highlighted the ability of the technology to drive performance and sustainability. As the A&D industry recuperates from the effects of the pandemic, we wanted to understand four things about its relationship with digital twin:

- Are organizations continuing to invest in digital twin?
- If they are, what's driving these investments?
- In which areas does digital twin add value?
- How can the organizations successfully scale their initiatives?

Our research reveals continued trust in the potential of digital twins in A&D. The share of organizations with a long-term roadmap for digital twins improved from 57% just eighteen months ago to 73% now. This interest in digital twin deployments is driven by both top and bottom lines. At 78%, technological advancement is the foremost driver of digital twin investments followed by operational efficiencies at 75%. Beyond these, digital twins also aid sustainability efforts in two ways: by reducing the carbon footprint of aviation and by enabling the virtual validation of the designs of green aviation alternatives, such as electric batteries and hydrogen fuel. Bridging the physical and the virtual worlds, digital twins drive design and operational efficiencies. A&D OEMs, suppliers, space companies, and airline operators are all investing purposefully in digital twin technology. Overall, the industry plans to invest 2.7 percent of its revenue in digital twin initiatives, a 40 percent jump from the previous year.

Executive summary

Through a combination of various digital twins, the A&D industry can improve every aspect of its value chain – from design to production to operations; the technology also supports collaboration within ecosystems, a key factor in thriving in the new business environment.

The research also looks into the industrial metaverse, which adds a new layer to digital twin, meaning organizations can interact in a more realistic environment – the 'internet of twins.' Our research found one in three organizations is already looking into the industrial metaverse or plans to do so within the year, with immersive training and real-life testing being particular areas of interest.

While digital twins have numerous applications, there are certain prerequisites for organizations to realize its full potential. A supportive infrastructure including digital continuity, cloud, connectivity, and technical capabilities that allow a seamless integration of digital twins with the various systems is a necessary foundation. Then, a digital thread that can feed data to the twin from various source types is critical, along with a program governance that drives an agile culture. Aircraft OEMs can also drive interoperability and collaborate with suppliers, peers, consultants, and system integrators to leverage synergies. Tier-1 suppliers need to focus on building a range of capabilities such as data integration, simulation, and project-management to seamlessly work with both aircraft OEMs and tier-2 suppliers. Defense organizations will need to strengthen the security of their networks while also developing their AI and ML capabilities. By focusing on these, all industry players can populate the new era of transformation that we call "Intelligent Industry."

Defining digital twins

A digital twin is a virtual replica of a physical asset, system, or process that can monitor, model or simulate, analyze, and optimize the physical world. It aims to bridge the physical-digital gap at the right frequency and fidelity, enabling continuous improvements to performance and sustainability. It establishes a closed-loop approach to unlocking hidden value, introducing synergies across data, technologies, and business processes, which puts it at the core of Intelligent Industry transformation. Through its ability to answer questions such as “what is best?”, “what if…?”, and “what next?”, digital twin technology not only provides visibility of how dynamic, real-world systems are currently performing and suggestions as to how to improve them, but also predicts performance in different scenarios. More than one digital twin may be applied to a product or system, depending on the stage of the life-cycle that requires it. Even within the same phase of the life-cycle, a digital twin need not necessarily follow a monolithic model but, rather, comprise a set of connected models of various kinds, each representing a different aspect of the real system (e.g., flow, physics).

Two other concepts often connected with digital twins are digital thread and model-based systems engineering (MBSE). A digital thread is a communication framework connecting a manufacturing company’s value chain. It integrates data on design, manufacturing, operations, quality, and service into an on-going cumulative flow that provides program managers with real-time information about product and service lifecycles on the go.[6] While digital twins provide a virtual representation of the physical system along with all the controls and workflows at a particular point, a digital thread provides a virtual record of all the states of a product or system over its life-cycle. MBSE refers to the application of models as opposed to documents to support system development (system requirements, design, analysis, verification, validation). MBSE is not limited to model-based design. It also creates a link between requirements and low-level high-fidelity technical models, acting as an enabler for digital twins.

"Our digital twin allows us to model, simulate, and scale a wide range of situations for critical stakeholders, including drone and aircraft pilots, operators, regulators, and the UTM [unmanned traffic management] service providers themselves."

Max Egorov Nova

Airbus UTM's Head of Simulation

Types of digital twins

There are different types of digital twins for different systems. Here we consider three broad categories of twins relevant for the A&D industry.

- Product/asset twin: It can be utilized in design and development to enhance product design, shorten time to market, and ensure engineering-manufacturing continuity. Asset twins are similar to product twins, but the lifetime of assets involved here is longer (often in decades) compared to a product twin.

- Process twin: A digital twin can be used to optimize a manufacturing process (a manufacturing twin) or any measurable and monitorable process. Digital twins can optimize industrial systems through the integration of resources, processes, and products, increasing system output and enabling scalability.
- Network twin: Organizations can increase performance, resilience, and sustainability for enhanced customer-centricity by using digital twins to simulate various networks. Supply chain twins, logistics twins, and transportation twins are some examples.

Several large aviation OEMs have made considerable progress in developing digital twins. This array of digital twins allows the OEMs to collect individual data generated during the manufacturing process and the in-service life cycle. For example, while a manufacturing twin can provide feedback on the quality and speed of the manufacturing process, an asset twin can provide information for new product development or intelligent after-sales services or maintenance.

In order to maintain and run its Runway 18R/36L and Terminal D, the Dallas/Fort Worth Airport (DFW Airport) created its own digital twin, populated with airport data gathered over a 40-year period. Airport management is hoping for an enhanced passenger experience based on the real-time situational awareness and operational efficiencies the technology introduces.[7]

Digital twin can also make improvements in much more dramatic circumstances. When a hurricane destroyed 60 percent of the Tyndall Air Force Base in Florida, US in 2018, base authorities partnered with the US Army to create a digital twin of the base – a complete replica of physical assets, processes, people, and spatial layout. *"With digital twin technology, users are able to virtually step inside the base and experience construction plans first-hand. Being able to 'walk through' areas of new construction gives users the opportunity to offer feedback and make changes before actual construction begins,"* says Lance Marrano, a Senior Scientific Technical Manager on site.[8]

A&D INVESTMENTS IN DIGITAL TWINS INCREASE BY 40 PERCENT AS CONFIDENCE IN THE TECHNOLOGY GROWS

01

More organizations recognize the importance of digital twins than 18 months ago

Even compared with 18 months ago, interest in digital twin is hotting up. While, in 2021, fewer than 60 percent of organizations had a long-term roadmap for digital twin use, today, nearly three-quarters of organizations have one. There are multiple reasons for this development (see Figure 1).

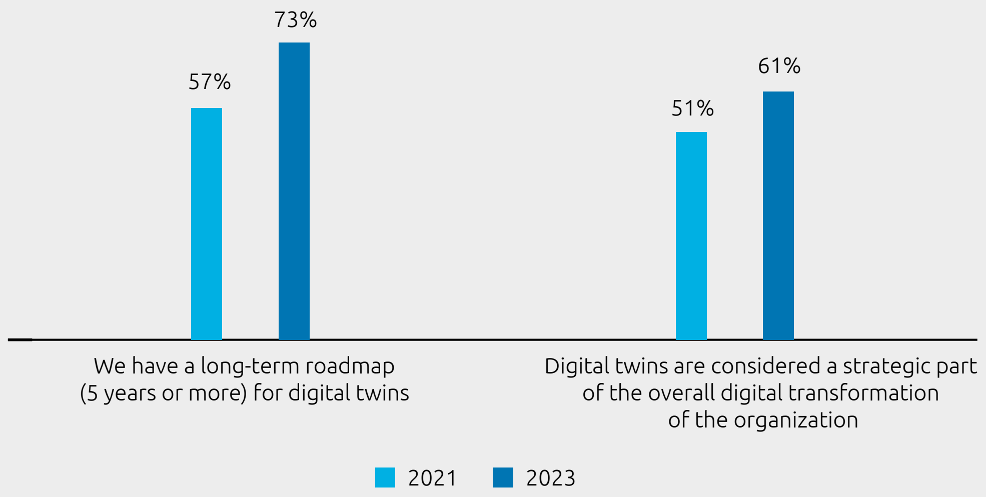
61%

of organizations consider digital twins a strategic part of their overall digital transformation

Figure 1

More organizations realize the importance of digital twins today compared to 18 months ago

INCREASED RECOGNITION OF THE IMPORTANCE OF DIGITAL TWIN TECHNOLOGY



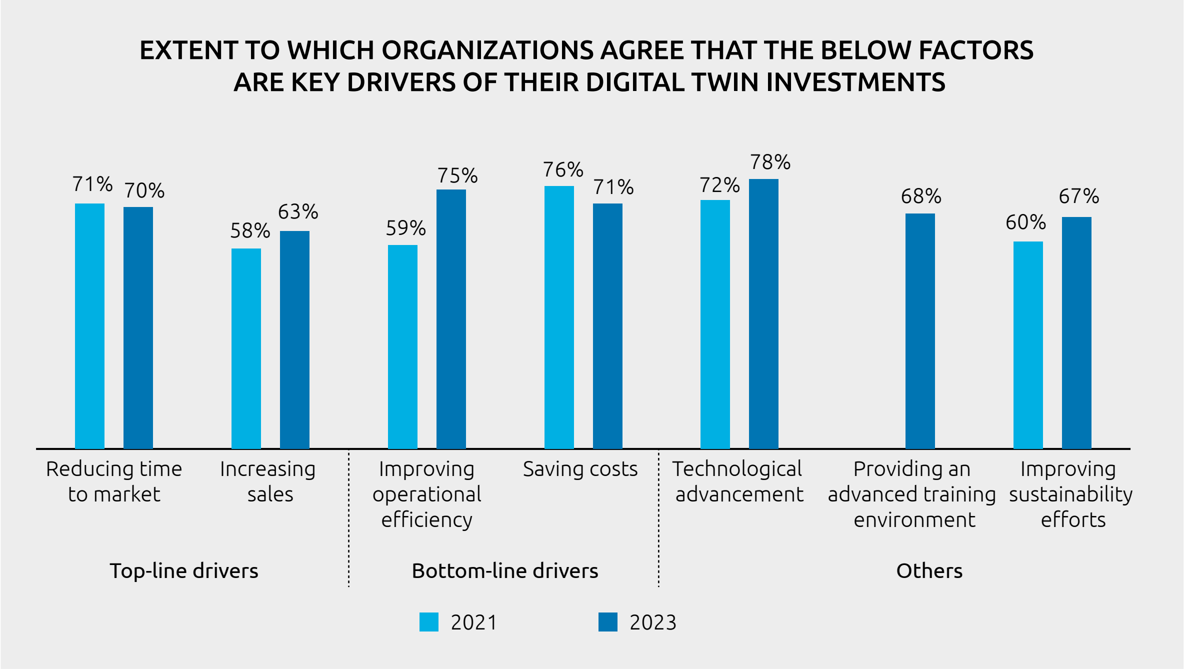
Source: Capgemini Research Institute, A&D Digital Twin Survey, April 2023, N=150 A&D organizations; Multi-Sector Digital Twin Survey, September–October 2021, N=87 A&D organizations.

Beyond the technological advancement mentioned by 78 percent of organizations, digital twins can help realize enhanced operational efficiency, leading to significant cost savings. This is a key driver of investment in digital twins but, as Figure 2 shows, there are other significant drivers. For example, while aircraft simulators have been around for decades, digital twins could be used to extend this concept for aerial-combat scenarios. The virtual twin of a real fighter pilot offers powerful insight into the performance potential of the pilot for real missions, allowing them to identify areas for improvement in terms of both tactics and execution.[9] Interestingly, there has also been a slight dip in the share of organizations investing in digital twins primarily to save costs, possibly owing to a lack of awareness of the range of cost-saving use cases.

Vitally for the A&D industry in particular, digital twins can improve revenue without compromising on safety. For example, while every aircraft has a Maximum Take Off Weight (MTOW), the

Figure 2

Both top-line and bottom-line considerations drive digital twin investments



Source: Capgemini Research Institute, A&D Digital Twin Survey, April 2023, N=120 A&D organizations with ongoing digital twin initiatives; Multi-Sector Digital Twin Survey, September–October 2021, N=85 A&D organizations with ongoing digital twin initiatives. The 2021 study did not have "providing an advanced training environment" and hence no data is shown here.

weight limits imposed are typically lower than this. Using digital twins coupled with weather and flight profile data, it is possible to better estimate the required load without overloading the aircraft (in the process saving fuel).

Sustainability is another important driver of investment in digital twins; technology is improving the efficiency of flight engines, shrinking the industry's carbon footprint. *"Since 2014, we've helped one of our airlines avoid 85 million kilograms of fuel and over 200 million kilograms of carbon dioxide,"* says Stuart Hughes, Chief Information and Digital Officer at Rolls-Royce. *"We did that by taking data on how the pilot is flying the plane, how the plane is operated, how they do the operational funding around that. We found data and insights that helped them to make better decisions. In areas where they felt there were barriers to change, we helped them design new policies, new procedures."*[10] While Rolls-Royce has been monitoring engines remotely for twenty years, with digital twins, they are able to treat each physical engine as unique, compare each physical instance to the twin, and optimize the performance.

78%

of organizations say technological advancement is the key driver of their digital twin investments

A&D organizations plan to invest 2.7 percent of their revenue in digital twin initiatives

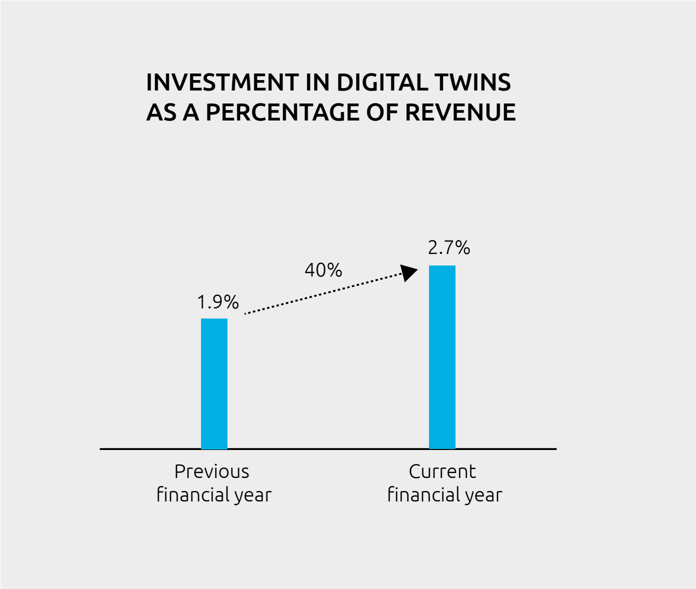
With all these drivers, it is no surprise that respondents in our research are planning to invest 2.69 percent of their revenue in digital twins, a 40 percent increase from last year. These numbers clearly highlight the industry's newfound confidence in the benefits of digital twin technology.

40%

jump in planned investment by A&D organizations in digital twin initiatives

Figure 3

Investment in digital twins has increased by 40 percent in the past year

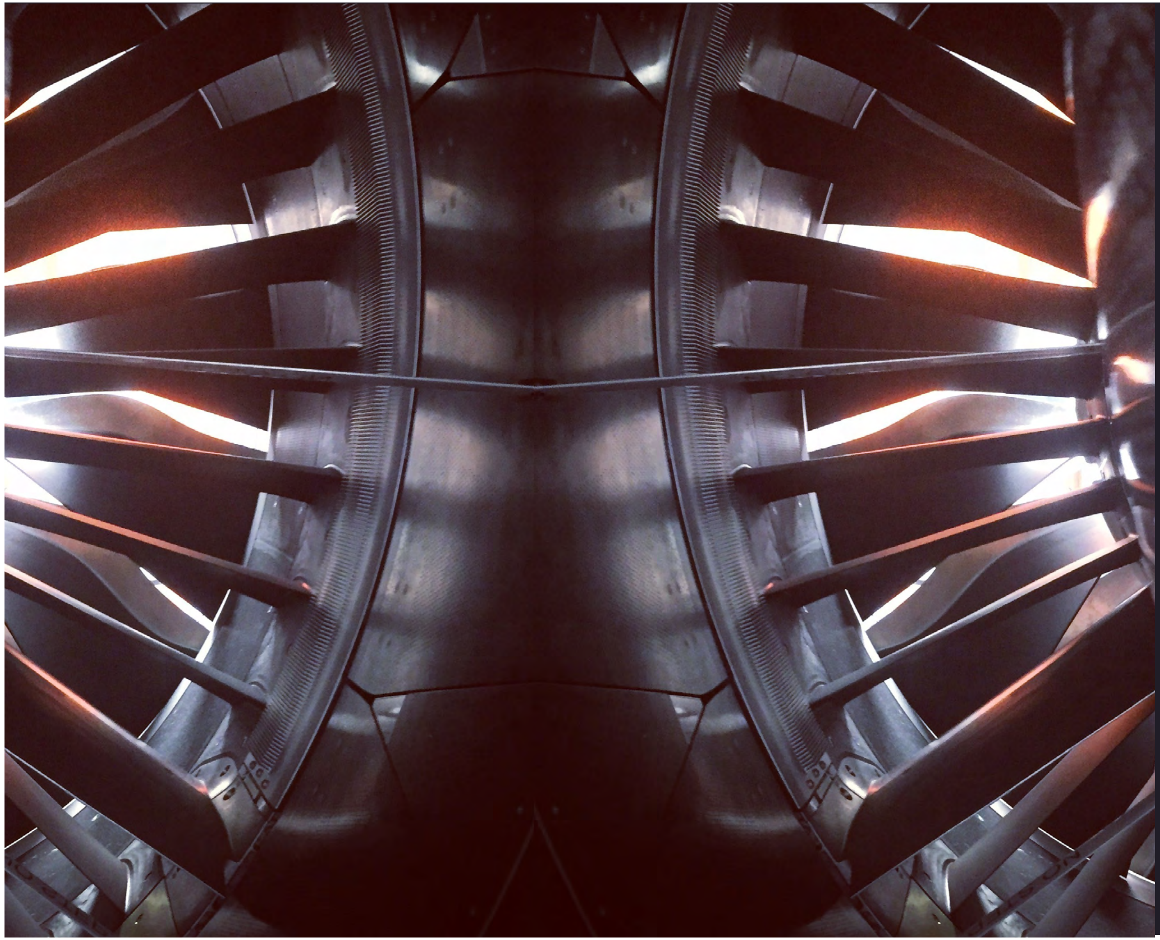


Source: Capgemini Research Institute, A&D Digital Twin Survey, April 2023, N=150 A&D organizations.

Digital twins promote efficiency by design

Seventy-five percent of organizations in our research say digital twins improve value from the outset of the design process. Digital twins can be particularly helpful in aerodynamic design for the electric vertical takeoff and landing (eVTOL) industry. As the concept of urban air mobility (UAM)[11] continues to gain traction, design teams and engineers working in this space need to consider a number of variables: weight, speed, performance, altitude, battery capacity, etc. A digital twin that considers all these variables and the influences that adjust them, such as electromagnetics and heat transfer, will allow engineers to simulate different scenarios and thereby optimize performance.[12]

EUROCONTROL (ECTL), a pan-European, civil-military organization dedicated to supporting European aviation, signed a memorandum with Airbus UTM to collaborate on the simulation of unmanned aircraft systems (UAS) and UTM. The Airbus UTM digital twin allows stakeholders to quantify the safety of various traffic scenarios. This collaboration aims to provide a framework for the partners to quantify and analyze U-space.[13]

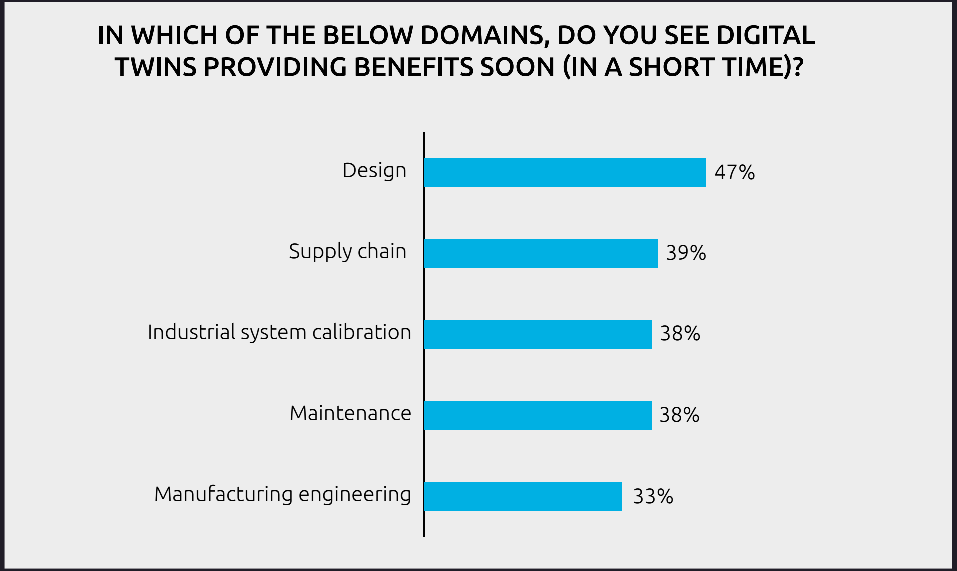


Digital twins can realize benefits quickly across a variety of domains

We asked organizations where they see digital twins providing the most immediate benefits; the design phase was cited by nearly half. They are also considered helpful during engineering and even in optimizing supply chains. *"We're moving to model-based engineering digitizing our entire engineering and development system up front, including down into our supply chain and connecting that with the production system and how we service and support to create value for our customers,"* enthuses Boeing's former CEO. *"That digital life cycle – think of it as a digital twin of our airplanes – will unleash incredible value in the future."* [14]

Figure 4

Nearly half of organizations cited quick benefits during the design phase



Source: Capgemini Research Institute, A&D Digital Twin Survey, April 2023, N=120 A&D organizations with ongoing digital twin initiatives.

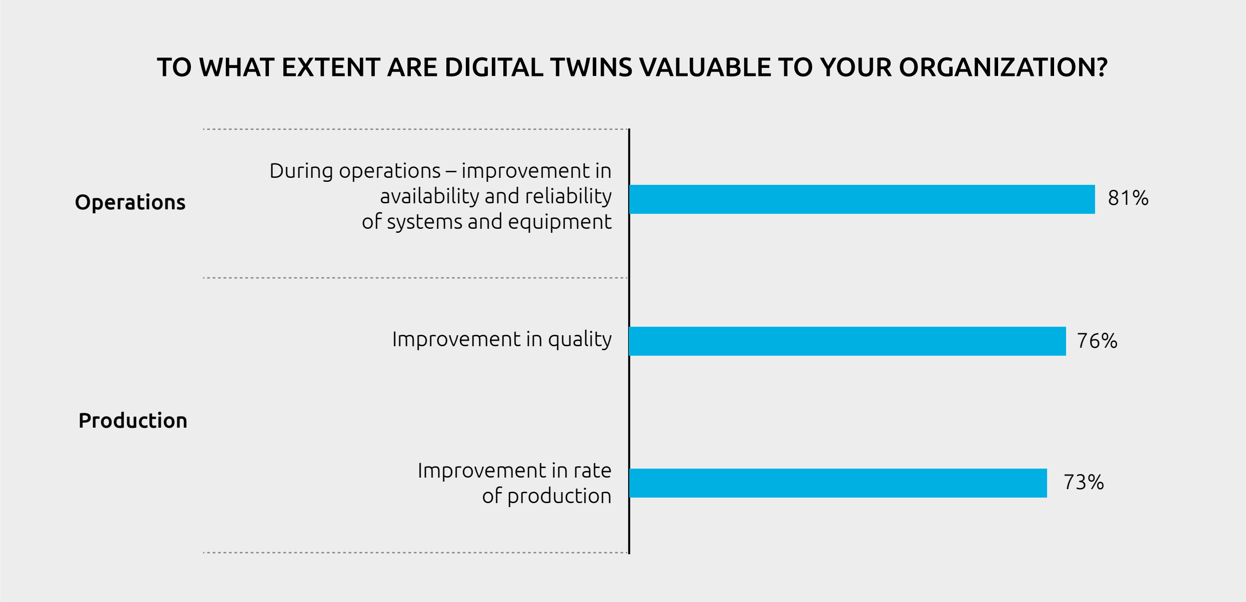
Digital twins give an operational boost

Beyond design efficiencies, as seen in Figure 5, the majority of respondents from our survey agree that digital twins streamlines production and operations.

The defense industry, in particular, relies on digital twins to improve systemic performance. For instance, the US Air Force Research Laboratory (AFRL) has developed a virtual twin of a collaborative "swarming" weapons system prototype, called "Gray Wolf," as part of its WeaponONE (W1) program.[15] This digital twin, a combination of an asset twin and network twin, incorporating AI and machine-learning (ML) capabilities, is able to determine improvements in its physical counterpart in near-real-time or as early as within the next 24-hour ATO (Air Tasking Order) cycle.[16] W1's portfolio includes a digital twin lab. Colonel Garry Haase, Director of the AFRL Munitions

Figure 5

Four in five organizations find digital twins valuable in improving the availability and reliability of their systems and equipment



Source: Capgemini Research Institute, A&D Digital Twin Survey, April 2023, N=120 A&D organizations with ongoing digital twin initiatives.

Directorate, expands: *"The Digital Twin Lab represents the ultimate expression of digital engineering, acting as a force multiplier, giving us tremendous flexibility and adaptability to our weapons systems."*[17]

Digital twins can assist in the sustainment (maintenance) of aircraft and facilitate their modernization. The US Air Force has partnered with National Institute for Aviation Research (NIAR), the aerospace R&D arm of Wichita State University, to create digital twins of F-16s[18], with the project intending to collect the data required to keep the fleet operational. *"Developing a virtual engineering environment that integrates structures and systems components will provide a virtual testbed for future modifications and other sustainment actions prior to physical implementation. Virtually testing prior to implementation will streamline the process, reduce airframe downtime, and increase mission readiness of this key military asset,"* says Melinda Laubach-Hock, NIAR F-16 Program Manager and Director of Sustainment. This example highlights how an asset twin can combine with a digital thread to save costs and augment system readiness.

"The Digital Twin Lab represents the ultimate expression of digital engineering, acting as a force multiplier, giving us tremendous flexibility and adaptability to our weapons systems."

Colonel Garry Haase

Director of the US Air Force Research Laboratory (AFRL) Munitions Directorate

Virtual commissioning and its benefits

Virtual commissioning, one of the use cases of digital twins, refers to the use of modelling and simulation technology to commission automation systems and validate software, system functionalities, and upgrades virtually, before deployment to the real system. Commissioning can contribute to up to 25% of the lead time for plant engineering and start-up.[19] Here are three business use cases of virtual commissioning covering different scenarios:

- Ensuring the safety of manufacturing systems is vital. Manufacturing systems must be designed to guarantee safety – that the asset is safe to operate, and the standard operation of the asset does not cause environmental damage. Virtual commissioning can:

- Minimize the risk of harm and loss by validating the preventive and mitigation measures implemented in the systems
- Achieve increased robustness by challenging safety implementation through the simulation of unsafe scenarios
- Minimize the environmental effect of the manufacturing system's operation and processes

• Software validation and optimization can be used to de-risk implementation and improve operations. Manufacturing software is developed separately from the physical industrial assets. Virtual commissioning allows engineers to validate functional models before deployment. This helps:

- Increase the availability of manufacturing systems
- Optimize system performance
- Reduce the risk of increasing the time to market

Let us consider a high-level hypothetical example of a manufacturing line in a factory producing goods worth of $25,000/hour on a three-shifts basis. Virtual commissioning can facilitate fewer project delays than typically occur during commissioning and production ramp-up, thereby avoiding losses due to production downtime and delays in the time to market. The following scenario illustrates the magnitude of the potential benefits: A two-day delay during production ramp-up of the manufacturing line is incurred due to machine software issues. This delay incurs losses of $1,200,000. Virtual commissioning can identify and solve these issues virtually in the office before deployment on-site, thus ensuring a smooth production ramp-up and a minimized risk of economic loss.

• Virtual commissioning can help train production and maintenance personnel in representative environments with real-system behaviors to support commissioning and production ramp-up. This further helps:

- Reduce downtime risks due to employee ramp-up
- Decrease response time against critical incidents

Source: Capgemini's industry expertise.

DIGITAL TWINS HAVE NUMEROUS APPLICATIONS ACROSS THE VALUE CHAIN

02

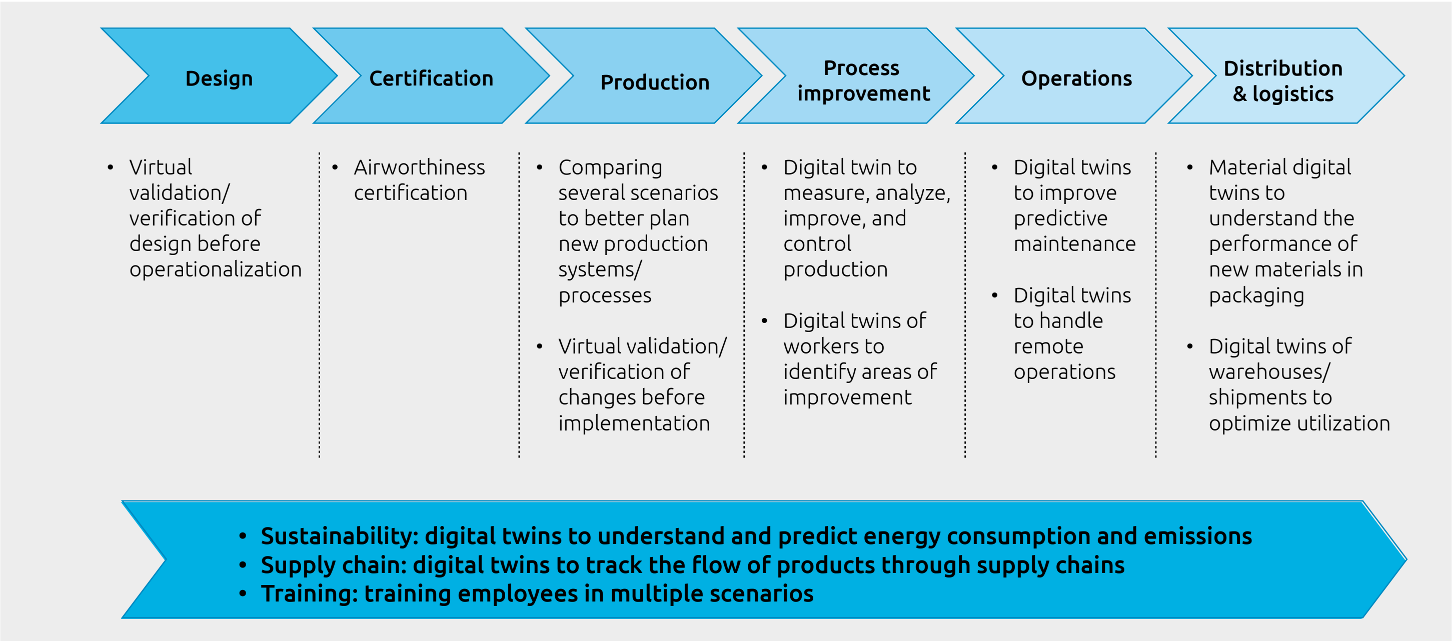
Each type of twin (see Introduction) or combination of twins can be used to improve every aspect of a value chain. Figure 6 details a number of use cases relevant to the A&D industry.

75%

of organizations say digital twins improve value from the outset of the design process

Figure 6

Digital twins can support various applications across the value chain



Source: Capgemini Research Institute analysis.

Design

Virtual validation/verification of design before operationalization:

This use case involves using digital twin models to validate designs prior to manufacturing parts. This not only cuts development time and costs, but it can also improve product safety. For instance, as Greg Manuel, Vice-President and General Manager at US A&D company Northrop Grumman, elaborates: *"…[Our team is] building a digital twin capability to continuously visualize, integrate, and test the system design. This allows us to identify and eliminate issues before creating the physical representation, while operating with speed and agility in meeting our program schedule."*[20]

Further, in an example highlighting model-based design, Gerardo Olivares, senior research scientist and director at NIAR, elaborates that the development of a pilot seat typically takes 24–32 months from conceptual design to certification, and could cost up to $3.5 million between the physical prototypes and the engineering. However, with the help of model-based design, testing and design could be done virtually, with less than $1 million in costs, taking only six months to complete.[21]

Certification

Airworthiness certification:

Certifying the airworthiness of an aircraft is a long and complex process, involving design review, ground and flight tests, and operational suitability evaluation, among other steps. Certifying a new aircraft type can take five to nine years.[22] While regulators still rely on physical testing of the aircraft, use of a digital twin and a digital thread across the entire product and service life cycle will help OEMs prepare for this certification, allowing them to navigate the certification process in a more efficient manner.

30%

Reduction in cleaning time achieved by KLM Royal Dutch Airlines by using digital twins to train ground crews on cleaning the Boeing 787 Dreamliner

Production

Comparing several scenarios to better plan new production systems/processes:

A process digital twin can be used to compare designed models (model-based manufacturing) to the actual production on the shop floor. This type of digital twin allows manufacturers to find the best option among a variety of scenarios, with varying numbers of phases, production lines, shifts, and employees. The concept can be further extended to a digital twin of production. In such a twin, entire manufacturing operations, along with the factory floor, employees, and machines, are recreated, allowing engineers to observe how they interact with each other and how materials move around the facility. Other industries, such as automotive, have already successfully developed factory digital twins, benefiting productivity without a loss of agility.

Virtual validation/verification of changes before implementation:

Similar to the first use case, this involves digital twins used to virtually validate the system against design, functional, and performance requirements prior to manufacturing. This facilitates a reduction in operating costs while avoiding costly late redesigns.

Process improvement

Digital twins to measure, analyze, improve, and control production:

Similar to a product digital twin, a process digital twin can simulate an entire production process, helping engineers detect process flaws before production commences.

Digital twins of workers to identify areas for improvement:

Distribution and fulfillment processes, as well as employee performance during loading/unloading, for example, can all be improved with the aid of digital twins. Here, digital twins support improved time allocation for worker operations and ergonomic and health and safety conditions.

Operations

Digital twins to improve predictive maintenance:

Digital twins enable earlier defect detection and reduce physical-asset downtime. Laura Szypulski, Director of Digital Transformation Strategy at Northrop Grumman, explains: *"If you've got a synchronized digital twin, you can project forward and determine when you need to send somebody out in the field to replace something, such as an antenna element, or run trades so you can take the least expensive or most effective path forward before you are affected by something."*[23]

Digital twins to handle remote operations:

Manufacturers can use digital twins to handle inspection and maintenance of their assets, without having to access the asset physically. At SpaceX, mission-control operators use a digital twin of the Dragon vehicle connected to hundreds of sensors on the spacecraft to monitor its trajectory, loads, propulsion systems, etc.[24] This enables improved reliability and safety of the vehicle.

Distribution and logistics

Material digital twins to understand the performance of new materials in packaging:

Digital twins are essential to ensuring that raw materials and finished items are packaged in the optimum volumes and sent to the correct destinations. Digital twins' ability to replicate package forms and packaging materials improves defect-testing cycles prior to deployment and lowers financial and environmental costs.

Digital twins of warehouses/shipments to optimize utilization:

Digital twins can optimize distribution processes, assisting in the discovery of inefficiencies and cutting lead times. During supply-chain disruptions, digital twins of supply networks can assist managers in understanding the impact of one variable – a supplier's plant shutting down, for instance, or the price of a component increasing – on the rest of the network, prompting necessary corrective actions.

Sustainability

Digital twins to understand and predict energy consumption and emissions:

There are a number of ways in which digital twins can aid sustainability. They help organizations improve resource utilization, reduce carbon footprints (as seen in the Rolls-Royce and YVR examples), and enhance employee safety.

Supply chain

Digital twins to track product flow through supply chains:

System-level digital twins can be used to monitor networks: for instance, real-time tracking of military operations for personnel, equipment, weapons systems, and essential supplies (food, water, and fuel). The US military has also tried to ensure the integrity of its semi-conductor supply chain by employing digital twin technology to verify the provenance of the components.[25] This helps create a trusted ecosystem of chips.

Training

Training employees/a workforce in multiple scenarios:

KLM Royal Dutch Airlines uses digital twins to train ground crews on cleaning the Boeing 787 Dreamliner, which has delivered a 30-percent reduction in cleaning time.[26] Today, KLM pilots can refer to a digital twin of an aircraft during their pre-flight safety check, while flight attendants can use them to locate safety items.

"If you've got a synchronized digital twin, you can project forward and determine when you need to send somebody out in the field to replace something, such as an antenna element, or run trades so you can take the least expensive or most effective path forward before you are affected by something."

Laura Szypulski

Director of Digital Transformation Strategy at Northrop Grumman

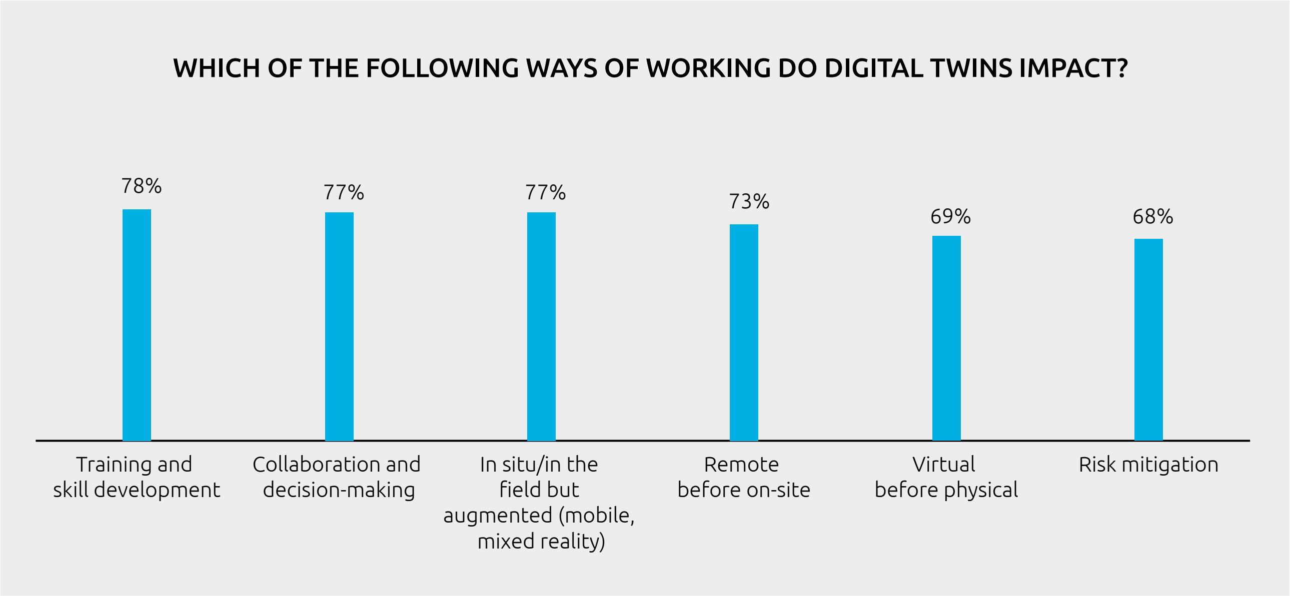
Digital twins enable collaboration

Not only do digital twins add value to various activities in the value chain, they can also transform work methods. Digital twins allow organizations to train employees from different physical locations. Seventy-eight percent of the organizations surveyed mentioned that digital twins affect their training and skill development (see Figure 7). Further, they allow design, engineering, and other teams to collaborate more easily. The data-management layer that digital twins provide delivers faster decision-making based on a single source of truth.

The “remote before on-site” advantage that digital twins afford is clearly beneficial in the space sector. SatSim, the digital twin of the Lockheed Martin Block IIR GPS satellite developed for the US Air Force Space and Missile Systems Center, allowed engineers to conduct vulnerability scans and penetration tests on the satellite.[27]

Figure 7

Digital twins allow teams to collaborate



Source: Capgemini Research Institute, A&D Digital Twin Survey, April 2023, N=120 A&D organizations with ongoing digital twin initiatives.

Digital twins aid sustainability efforts

Sustainability is another strong driver of digital twin investment. The carbon footprint of air travel is a major issue for the industry, which emitted more than 1 billion tonnes of CO_2 in 2018.[28] While the industry is working on various fronts, including electric and hydrogen-powered aircraft and lighter and more heat-resistant materials, digital twins can play a critical role in developing solutions to reduce this footprint. Two in three (67 percent) organizations in our research mentioned that improving sustainability is a key driver of their digital twin investments, up from 60 percent in our previous survey.

Rolls-Royce has deployed digital twin technology and ML to optimize maintenance of aircraft engines, allowing airlines to keep their planes in the air for longer. The company was able to extend time between maintenance, in some cases by up to 50 percent, resulting in savings of 22 million tonnes of carbon to date, while also enabling a reduced spare-parts inventory.[29]

While this example highlights the capability of digital twins to improve sustainability through operational efficiencies, they also play a key role in design. The aviation industry is considering both hydrogen fuel and electric batteries as decarbonization tools. However, both options have issues: batteries are heavy and hydrogen is difficult to store, meaning both necessitate changes in the design of aircraft. Digital twins allow engineers to validate each design decision virtually, cutting down prototyping as well as testing time and costs.

DIGITAL TWINS FORM THE BACKBONE OF THE INDUSTRIAL METAVERSE

03

The industrial metaverse is a virtual, 3D environment allowing businesses and individuals to collaborate on the design and testing of products, processes, and systems. The industrial metaverse further adds a new dimension to digital twins and supports the creation of an "internet of twins." A system-level digital twin can be constructed by connecting simpler, unit-level digital twins. Similarly, a system-of-systems digital twin is a network of such twins and can be used as a twin for an entire factory or a complex network. The industrial metaverse allows organizations to co-design and co-simulate by providing a way to model the specific universe representing the environment.

Three in four organizations believe that digital twins are the foundation of the industrial metaverse

Digital twins serve as one of the fundamental building blocks of the metaverse. The metaverse is intended to host precise reproductions of real environments and systems, with significant implications for the A&D industry. Our research shows that 73 percent of organizations are quite enthusiastic about the industrial metaverse and its implications for their businesses and operations. Further, three in four organizations we surveyed believe that digital twins are a key prerequisite for establishing the industrial metaverse. Apart from the industrial side, the metaverse also presents an opportunity to enhance product offerings and the commercial-passenger experience.

73%

of organizations are quite enthusiastic about the industrial metaverse and its implications for their businesses and operations.

One in three organizations (34 percent) has access to the industrial metaverse already or plans to implement it within the year

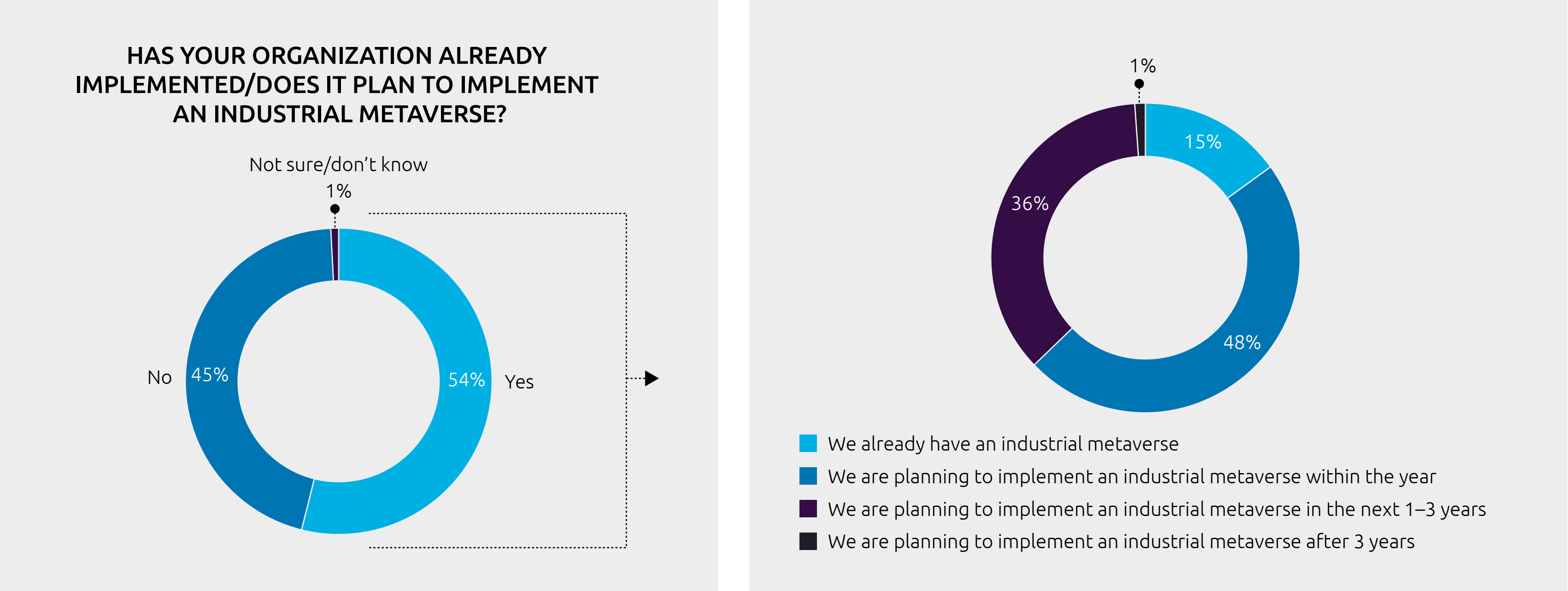
Our research found that 54 percent of organizations mentioned they already have access to the industrial metaverse or have plans to implement it. Of these 54 percent, 48 percent (26 percent of the overall sample) have plans to implement it within a year, while 15 percent (8 percent of the overall sample) already have an industrial metaverse.

8%

of organizations surveyed already have an industrial metaverse

Figure 8

One in four A&D organizations plans to have an industrial metaverse within the year, while 8 percent already have one in place



Source: Capgemini Research Institute, A&D Digital Twins Survey, April 2023, N=150 A&D organizations.

How are A&D organizations harnessing the industrial metaverse?

The industrial metaverse uses immersive technologies such as augmented and extended reality (AR/XR) to visually represent physical assets to comprehend how those assets materialize in the actual world. A&D organizations could adopt this technology in a variety of ways:

Design simulation

The process for designing any product or component, such as a propeller, can be undertaken in realistic environments. As previously highlighted, a digital twin could comprise a number of different digital twins. By using these digital twins, engineers can federate data across these various aspects and accelerate the multi-disciplinary development process. Similarly, the industrial metaverse could also be a place for the various players of the industry – OEMs, suppliers, and even regulators – to come together to analyze accidents and failures to improve airworthiness.

Factory operations

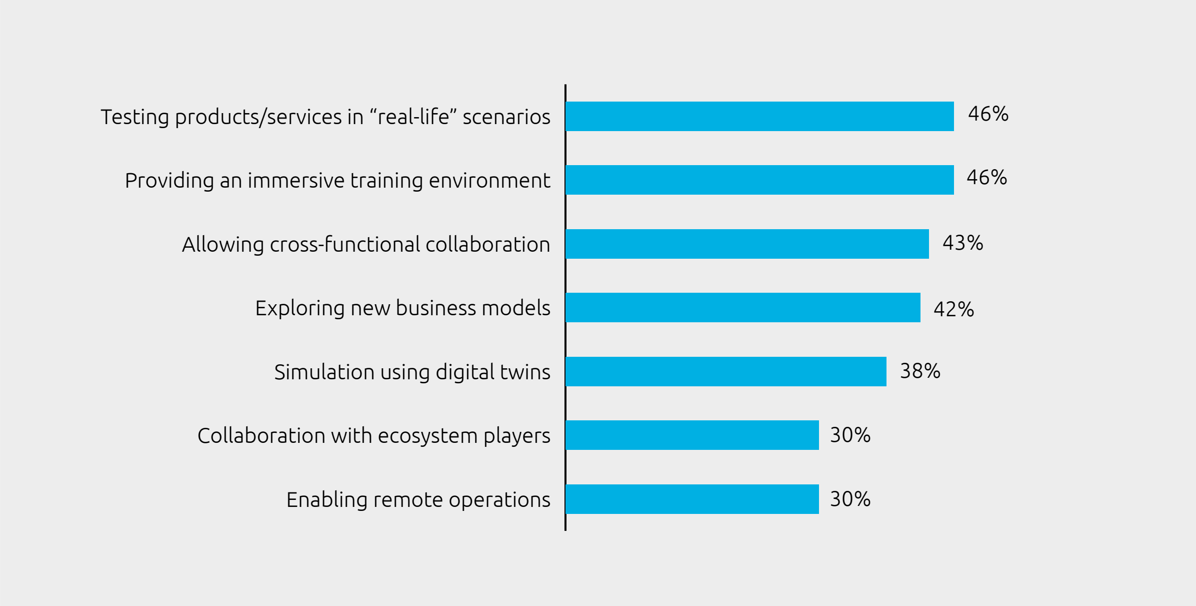
Metaverse technology allows plant managers to map the factory floor digitally, facilitating the visualization of human-machine interactions and optimal synchronization: where parts are stored, where to station the crews, and more. It allows a seamless transition from a digital work environment where employees can start a shift virtually (say a stand-up meeting) and be in front of their production environment physically. It could also help to identify resource constraints, bottlenecks, and waste.

Product servicing and maintenance

The metaverse allows A&D organizations to assess digital twins connected via a digital thread in their realistic environments. This can be used to predict how a particular part or engine might perform in that environment, thereby modifying the servicing cycle and extending component lifetime.

Figure 9

Immersive training and “real-life testing” are the top use cases for the industrial metaverse



Source: Capgemini Research Institute, A&D Digital Twin Survey, April 2023, N=81 A&D organizations that either have an industrial metaverse already or plan to implement it in the future.

Immersive training

As our research shows, immersive training is among the top use cases of the industrial metaverse (see Figure 9). Immersive training allows organizations to train their employees in realistic conditions, something that is particularly helpful in allowing operators, pilots, etc., to become accustomed to the environment without exposing them to physical risk. Rheinmetall, a German arms manufacturer, supplies AR-equipped rigs for training the maintenance and repair personnel of the A400M military transport aircraft to the Bundeswehr, the German armed forces.[30] These training rigs support effective training of maintenance personnel in a realistic reproduction of field conditions, without adversely affecting the availability and readiness of the A400M fleet.

As Figure 9 shows, in addition to an immersive training environment, “real-life” testing is another top use cited by organizations that already have access to the industrial metaverse or plans to implement it in the future.

Interestingly, the metaverse need not be limited to internal operations. Last year, Airbus invited companies to take part in the HeroX/Airbus Metaverse Challenge, in which it asked participants to imagine the "evolution of air travel" using the metaverse.[31] Capgemini's winning entry proposed a virtual town square that would "come alive" after takeoff, serving as a hub for passenger experiences and a platform for services such as in-flight shopping, ordering meals, booking hotels, and more. Other winning entries included multiplayer VR environments inviting passengers to socialize (allowing them to take 3D "walkarounds"), while also offering gaming and relaxation zones.

Airport operators are also tapping into the metaverse to provide a unique passenger experience. India's Bengaluru International Airport launched the BLR Metaport, in which visitors can experience its new Terminal 2 in an immersive, three-dimensional (3D) space. The 3D interface will alter how people use the airport, including check-in, navigating terminals, and shopping or socializing with other passengers. Users can even take a virtual tour of the new terminal via their smart devices.[32]

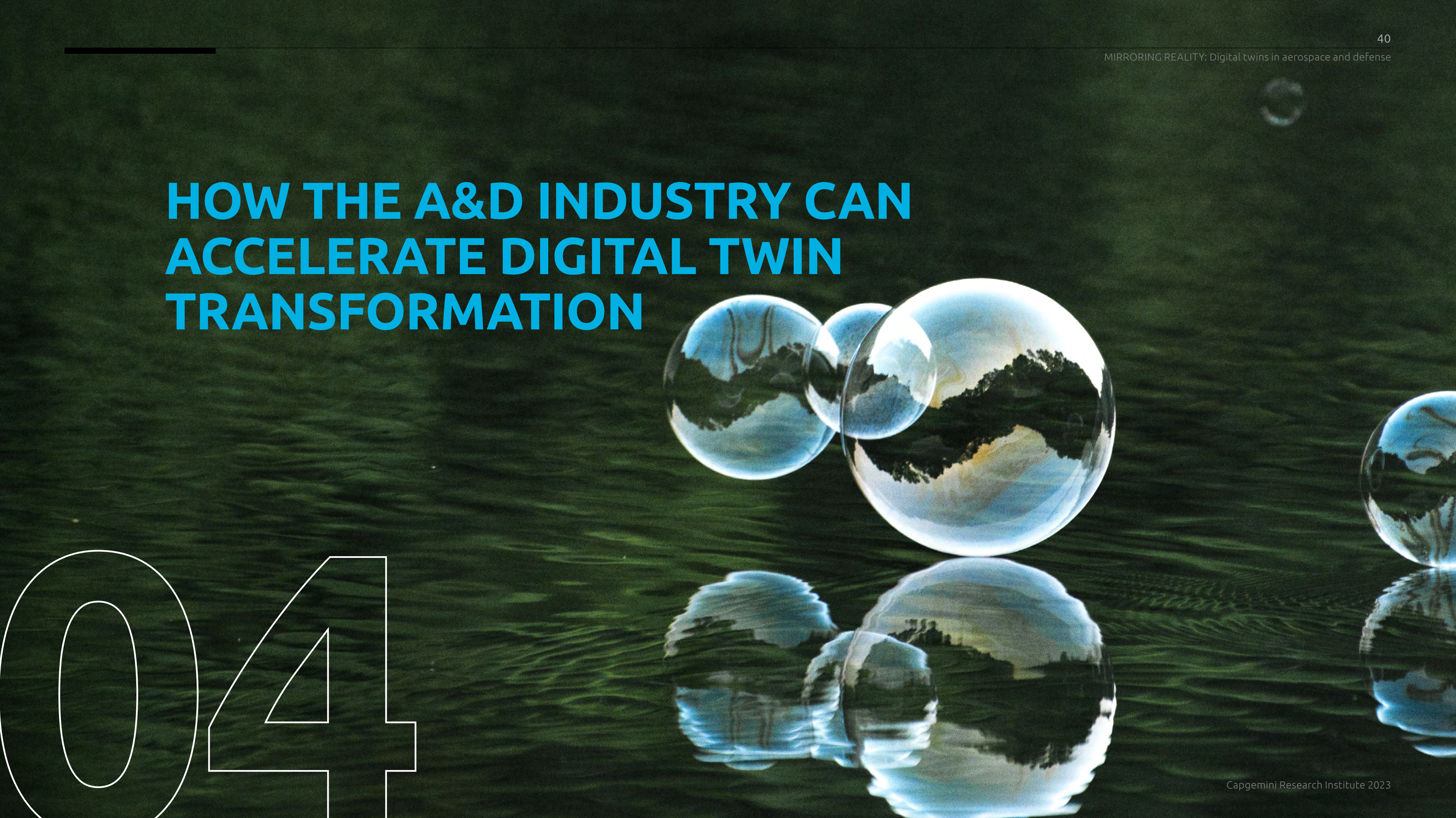
The metaverse offers organizations several options to enhance their internal operations and end-user experience, and also provides visibility into, and control over, processes that affect their top and bottom lines. Advanced air mobility (AAM) players are increasingly turning to digital twins and the metaverse, in addition to AI/ML, to solve their issues.[33]

Industrial metaverse further adds a new dimension to digital twins and supports the creation of an "**internet of twins**."

“Developing a virtual engineering environment that integrates structures and systems components will provide a virtual testbed for future modifications and other sustainment actions prior to physical implementation. Virtually testing prior to implementation will streamline the process, reduce airframe downtime, and increase mission readiness of this key military asset [F-16].”

Melinda Laubach-Hock

National Institute for Aviation Research F-16 Program Manager and Director of Sustainment



HOW THE A&D INDUSTRY CAN ACCELERATE DIGITAL TWIN TRANSFORMATION

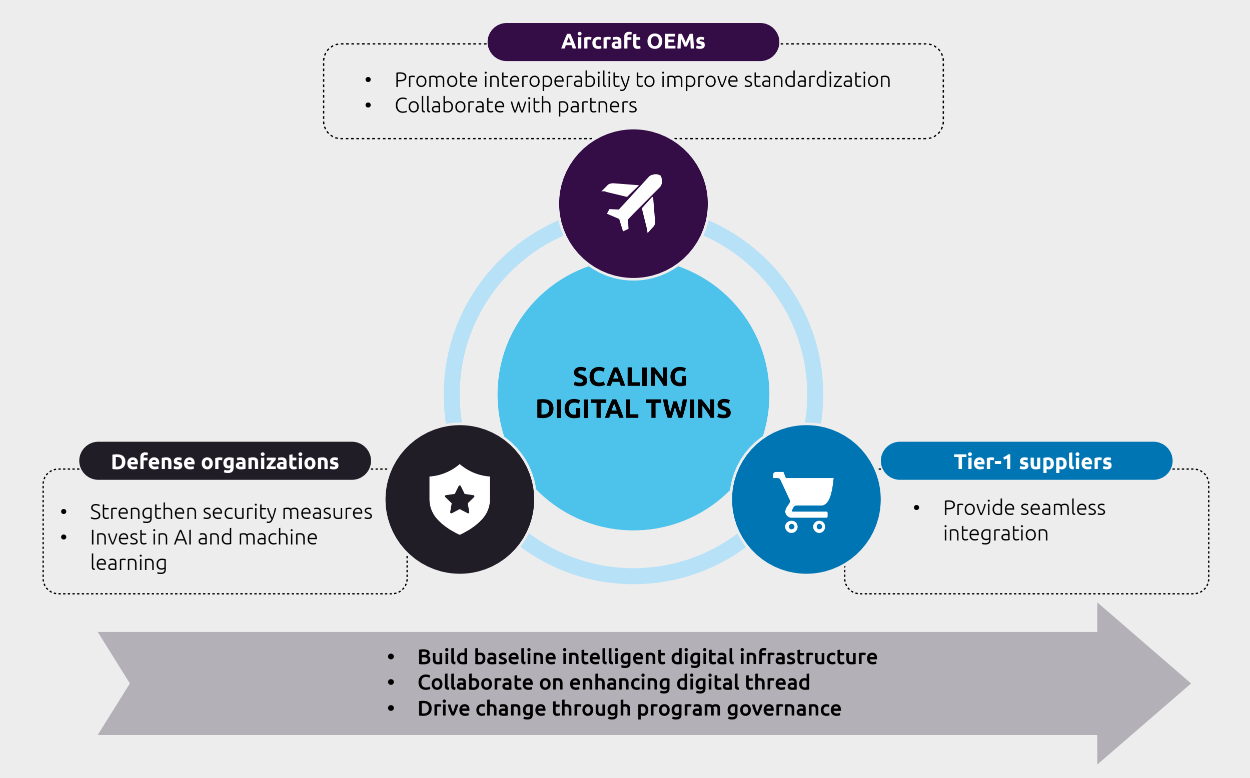
04

The previous sections highlight the numerous ways in which digital twins benefit the A&D industry. However, there are a few areas in which organizations need to invest to make their digital twin initiatives a success. Our previous research highlights a number of recommendations.[34] Based on the results of our current survey and on our market experience, we have identified a few areas specific to the A&D industry, as shown in Figure 10.

We start with a few areas that are applicable to all A&D organizations, whether OEMs, suppliers, or defense organizations.

Figure 10

Prerequisites for successful digital twin initiatives



Source: Capgemini Research Institute analysis.

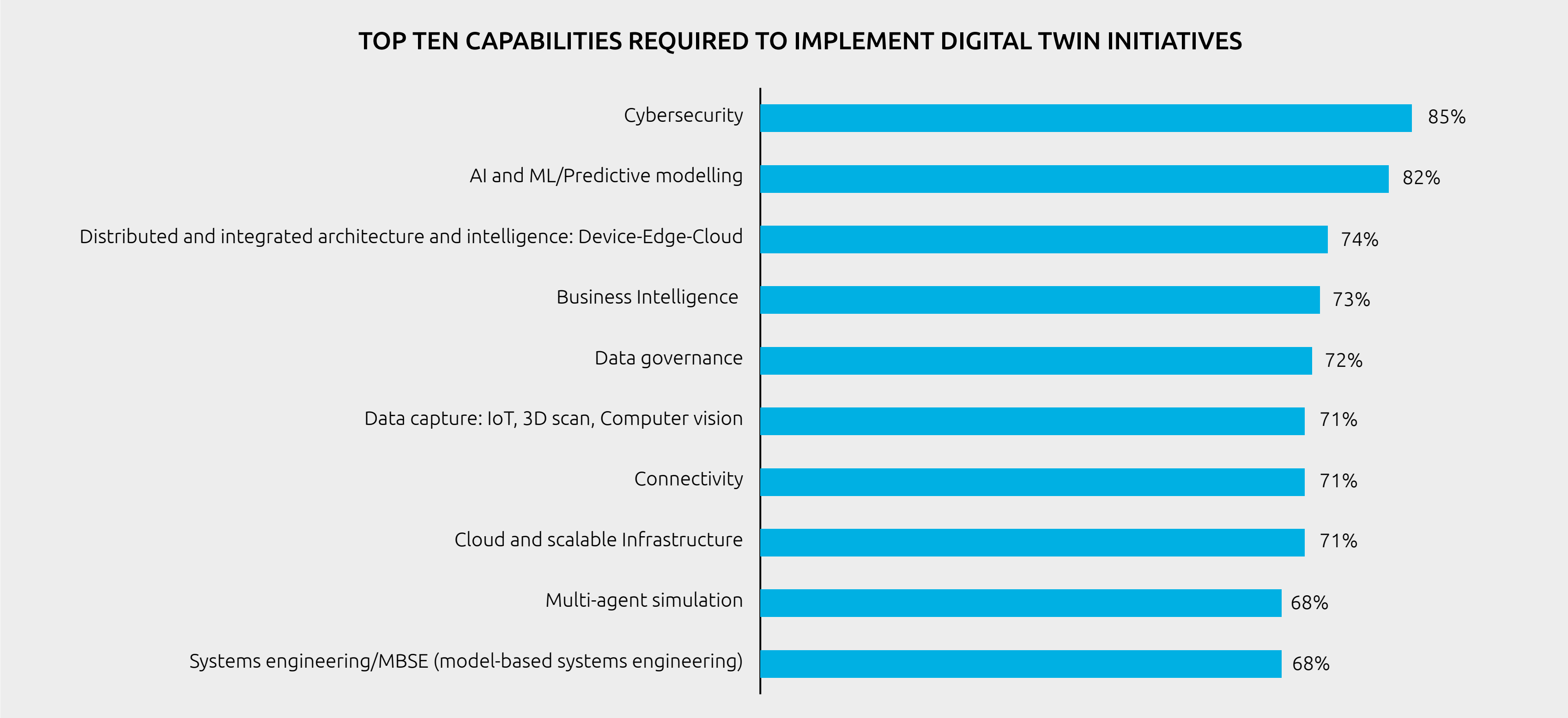
Build baseline intelligent digital infrastructure

Digital twin initiatives will involve changes across the enterprise and life cycle of the system to remove silos. To embed digital twins into the enterprise, organizations must plan for integration. Our multi-sector research provided a reference architecture framework for such an integration.[35] It is also important not to see digital twin initiatives in isolation. They can integrate very well with other ongoing enterprise efforts around model-based engineering and digital thread.[36] For digital twins to deliver the desired design and operational efficiencies, organizations need to ensure availability of the following elements:

- **Integration with existing systems:** A digital twin needs to talk to multiple systems, including product life-cycle management (PLM), manufacturing execution systems (MES), enterprise asset management (EAM), and enterprise resource planning (ERP). Smooth integration of these systems with the digital twin will allow the latter access to the data it requires. For a smooth integration, it is important to have a product configuration management with product breakdown structure identification, including the variants and product change management.
- **Cloud computing:** Digital twins can generate massive amounts of data. Cloud computing can help in storing and analyzing this data. It can also support digital twins in providing real-time updates. Further, it allows organizations to scale their storage and computing requirements as needed. At the same time, organizations must also invest in green IT to control energy consumption.
- **High-speed connectivity:** When digital twins are used operationally, poor network speeds negatively impact their ability to optimize and share feedback. High-speed networks facilitate real-time or near-real-time updates.
- **Digital continuity:** Digital continuity is the seamless flow of information throughout the product and service life cycle, from design to use. It covers end-to-end processes such as product/asset life-cycle management, supply-chain management, and asset or after-sales management. This digital continuity ensures that the digital twin has the right data and, therefore, can be used to replicate the physical system/process.
- **Technical capabilities:** Organizations must also invest in the technical capabilities required for a successful implementation of a digital twin. These include a broad range of skillsets and capabilities. Figure 11 highlights the top-ten skills that our survey respondents deemed important for digital twins.

Figure 11

Cybersecurity and AI/ML are the top capabilities required to implement digital twin initiatives



Source: Capgemini Research Institute, A&D Digital Twin Survey, April 2023, N=120 A&D organizations with ongoing digital twin initiatives.

Collaborate on enhancing digital thread

The value of digital twins lies in their ability to model, simulate, predict, and monitor physical counterparts. All of these require a data-management layer to integrate data from multiple sources. This layer serves as a single, up-to-date source of truth for various kinds of data, including "cold" data (e.g., historical-system specifications and models) and "hot" data (IoT, OT, real-time events); "descriptive" data (GIS, BIM, CAD/CAM, etc.); "transactional" (PLM, ERP, MES, etc.); and metadata. Digital thread captures the required data and feeds this into the digital twin.

However, having a single source of truth does not necessarily entail complete centralization of data computing and storage. Organizations must strike a balance in terms of data-sizing, computing, and synchronization. Seventy-eight percent of OEMs and tier-1 suppliers with ongoing digital twin initiatives agree that data management is important to harnessing the full potential of digital twins. Further, nearly 60 percent of these organizations also cite the lack of a unified data platform as a challenge in digital twin deployment.

Drive change through program governance

Large OEMs and even suppliers are often set in their processes from years ago. For example, if a new software needs to be introduced, the chief engineer must convince finance on the budget, engineers to try out the new tool, and others to invest in it. While such steps are necessary, they also reduce the agility of these organizations. It is important for a governance body to balance the tradeoff between set processes and agility. Surprisingly, only 41% of the organizations from our research agree that digital-twin program governance needs any change. The program governance body needs to steer the various teams with a clearly defined roadmap, by addressing the risks and bringing in an agile culture to ensure the digital twin initiatives are successful.

Aircraft OEMs: Promote interoperability to improve standardization

Any large system, particularly in the A&D industry, such as an airplane or a weapons system, will contain a number of subsystems, often designed by and procured from various suppliers. Similarly, industry also relies on a variety of software solutions, such as Catia (owned by Dassault Systems) and Siemens NX, for modeling. Achieving interoperability among these various parts and software is a challenge that could impede progress.

While OEMs do not design software or subsystems, they can work with suppliers to mitigate issues such as vendor lock-in and standardize specifications across suppliers, supporting interoperability. Secondly, they can join consortiums for the design and development of digital twins. Digital Twin Consortium is one such example, which counts GE Digital and Northrop Grumman among its steering-committee members. The consortium is hoping to drive interoperability through frameworks and open-source code.[37]

Aircraft OEMs: Collaborate with partners

Our research highlighted that organizations are either already working with or would prefer to work with various partners on digital twin initiatives. Nearly one-third of OEMs and suppliers (32 percent) ranked consulting firms and system integrators as their preferred partners, while 24 percent preferred consortiums. Consulting firms and system integrators can help organizations in many ways – building a roadmap, identifying quick wins, developing an architecture for a digital twin, data management, and even guidance for scaling initiatives.

Startups are another avenue through which to accelerate innovation. Lufthansa Technik Philippines, an aircraft maintenance, repair, and overhaul (MRO) service provider, launched its Startup Challenge in 2022. The company hoped startups could provide technology, for example for real-time tracking of tools and materials and digital and automated aircraft inspections.[38]

The Airport Cooperative Research Program (ACRP) in the US created a taskforce with the objective of composing a guidebook for the aviation industry, focusing on the development of aviation-specific digital twins. The ACRP panel comprises representatives from four major US airports: Dallas/Fort Worth International Airport, Hartsfield-Jackson Atlanta International Airport, Boston Logan International Airport, and Jacksonville International Airport. It envisions a future where every airport, regardless of air traffic or size, can use a digital twin to improve the airport experience.[39]

60%

of organizations surveyed cite the lack of a unified data platform as a challenge in digital twin deployment

Tier-1 suppliers: Provide seamless integration

Tier-1 suppliers work closely with OEMs during the design phase and are often deeply involved in the definitive design stage, as well as producing the parts and assembling and delivering the product to OEMs. It is therefore imperative for suppliers to have the same type of modeling system, even as that of the OEMs, according to CATIA, to ensure parts can easily integrate into the finished aircraft. At the same time, tier-2 and tier-3 suppliers will not have the same kind of systems, nor can they afford the level of investment required to facilitate vertical integration. This ensures that the responsibility to maintain uninterrupted workflow to the OEMs falls on tier-1 suppliers. Capabilities they should develop to ensure this integration include:

- **Data-integration capabilities:** In the absence of a standard data exchange format defined at industry level, tier-1 suppliers will need to integrate data from OEMs (such as product definitions, stress models, etc.), tier-2 suppliers, CAD models, and other sources in a format that is acceptable to OEMs.
- **Simulation capabilities:** These help in product optimization.
- **Project-management capabilities:** Tier-1 suppliers often need to translate design definitions into a format that works for their tier-2 suppliers, who may not have the same modelling software. They need to collaborate with their suppliers and ensure the specifications are clearly communicated.

Defense organizations: Strengthen security measures

While security is important for any digital twin, it is supremely important for defense organizations. By definition, a digital twin can monitor and optimize its physical counterpart, meaning an unauthorized user who gained access to a digital twin could gain control of the physical system. When this is a weapons system, there is a clear danger. With a digital twin, the “attack surface” is increased, so organizations must take sufficient steps to fully protect both the physical asset and the digital twin. Such measures include:

- **Active involvement of the chief information security officer (CISO):** The governance of digital twins is handled by various teams, as required.

Irrespective of who is managing the digital twin and its data, the CISO must plan and protect the entire network.

- **Data authentication:** The data that the twin shares, particularly any control signals that affect the state of the physical twin, should be authenticated.
- **IoT sensors:** Sensors used on the physical twin are potential vulnerabilities. It is important to authenticate every device transmitting over the network.

Nearly ninety percent of OEMs and suppliers surveyed highlighted cybersecurity as the top capability required for developing and improving digital twins.

Defense organizations: Invest in AI and ML

Next to cybersecurity, 82 percent of OEMs and suppliers mentioned AI and ML as the second-most important capability for developing digital twins. For defense organizations, this is critical to processing the copious amounts of data involved and planning optimum outcomes. Advanced analytical and modelling skills are necessary for digital twins to provide real-time insights in high-pressure situations.

Recognizing the need for a deeper understanding of AI and what it offers, organizations across the world are creating AI centers or academies. The UK's Ministry of Defence (MOD), for example, formed the Defence Artificial Intelligence Centre (DAIC) to accelerate and champion the development, use, and understanding of AI to achieve strategic outcomes. DAIC is also expected to enable adoption of AI across the MOD.[40]

The rise of generative AI also has a number of applications for the industry. GitHub Copilot, for example, improves the productivity of developers, helping them stay in the flow (73%) and preserve mental effort during repetitive tasks (87%), as per a large-scale survey of developers using Copilot.[41] Further, other use cases such as the generation of synthetic data and generative design will also be useful.

CONCLUSION

In an industry where product development can be a multi-year process, often requiring an equally exhaustive period of testing, and where assets cost tens of millions of dollars, digital twins provide a distinct opportunity for organizations to optimize design and streamline production and operation, lowering costs, reducing time to market, and improving safety standards.

Digital twins have applications in design, production, operations, maintenance, and training – in short, in every part of the value chain. And it is not only aerospace OEMs that can benefit from digital twins; the defense, space, and UAM industries should also welcome the technology. Furthermore, digital twins will play a key role in reducing organizations' carbon footprints. The industrial metaverse will enable collaboration across the value chain, as well as important applications such as "real-life" testing and immersive training environments. Recognizing the value of these performance advantages, the industry plans to invest significantly in digital twins over the coming years.

The full potential of digital twins remains untapped. Other industries have developed digital twins of entire factories, supply networks, and even nuclear reactors. Clearly, the A&D industry has much to gain by scaling its initiatives. This requires organizations to develop an infrastructure that offers digital continuity, connectivity, and a strong focus on data management. The OEMs with the deepest pockets can also drive initiatives by driving collaborative visions across ecosystems that result in viable, managed change and achievable standardization, allowing the whole A&D industry to count digital twin as a big part of its future.

RESEARCH METHODOLOGY

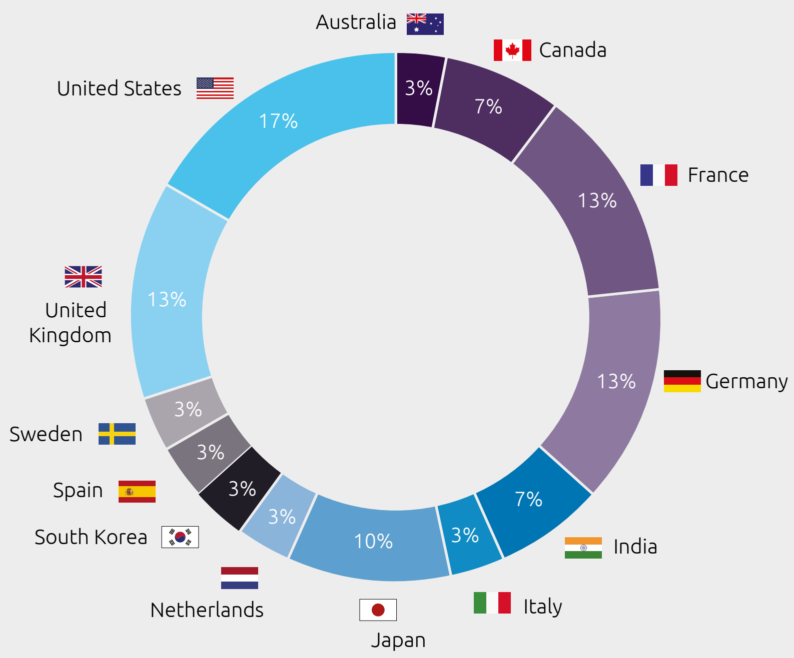
To understand how digital twins are transforming the A&D industry, we carried out a targeted survey. We supplemented this with interviews with senior executives from various OEMs and suppliers of the A&D industry to understand the various use cases and challenges they faced, and the capabilities required to scale digital twins.

Executive Survey

We surveyed 150 Aerospace & Defense organizations, 80 percent of which have an ongoing digital twin program, while the remainder plan to implement one. All these organizations have revenues of at least $500 million. The distribution of the organizations is provided below.

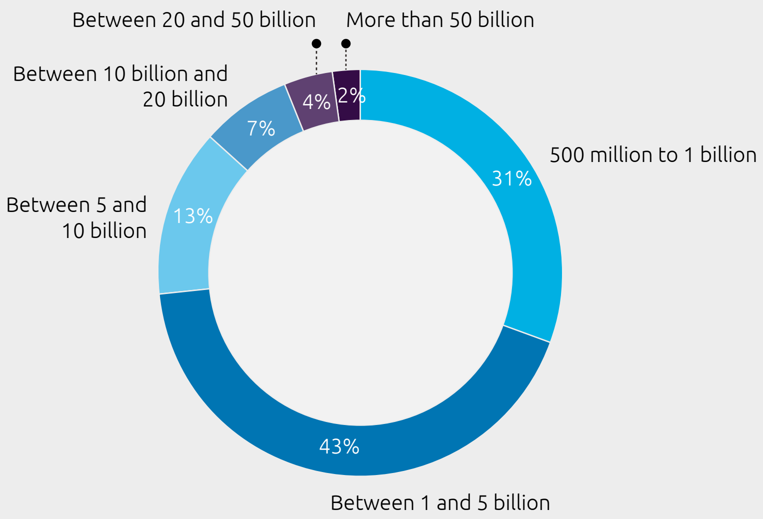
The study findings reflect the views of respondents to our online questionnaire for this research and are intended to provide directional guidance. Please refer to the methodology for details of respondents and contact a Capgemini expert to discuss specific implications.

COUNTRY OF HEADQUARTERS OF ORGANIZATION

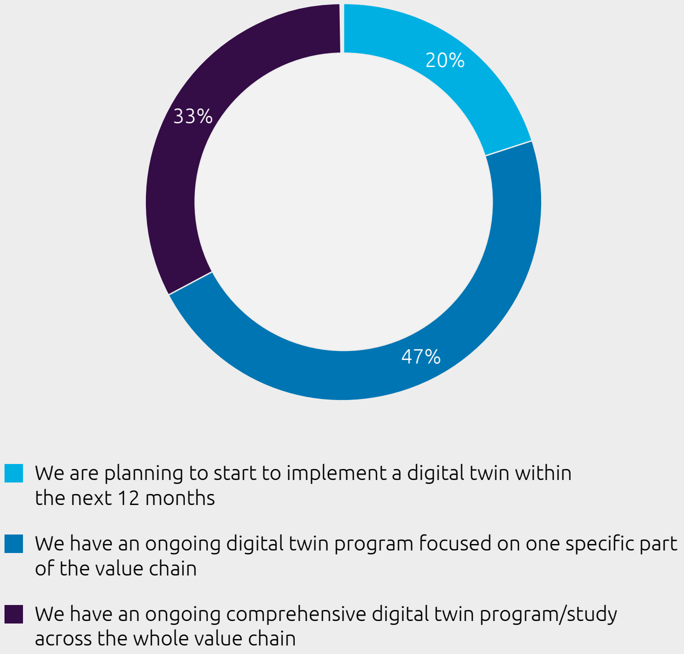


Source: Capgemini Research Institute, A&D Digital Twin Survey, April 2023, N=150 A&D organizations.

ANNUAL REVENUE OF ORGANIZATION (IN USD)

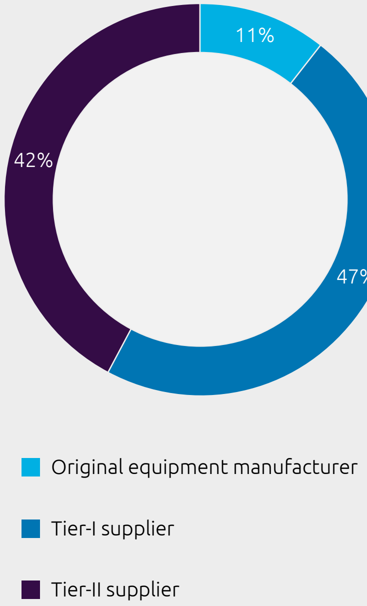


DIGITAL TWIN IMPLEMENTATION JOURNEY

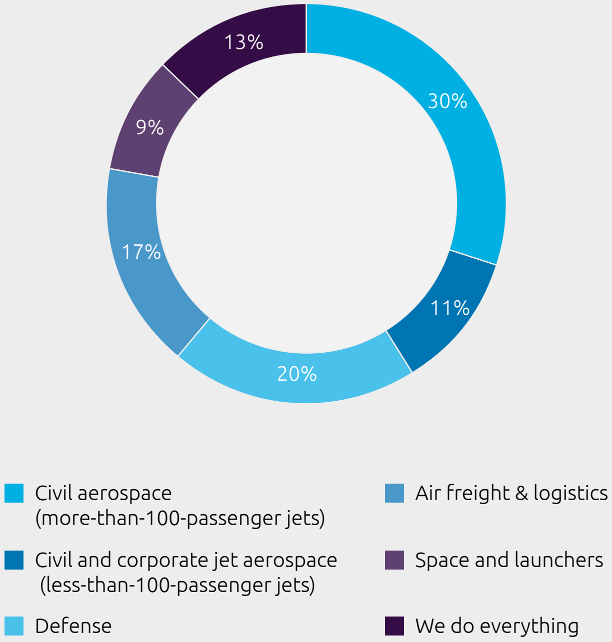


Source: Capgemini Research Institute, A&D Digital Twin Survey, April 2023, N=150 A&D organizations.

TYPE OF ORGANIZATION



DISTRIBUTION OF A&D ORGANIZATIONS BY OFFERING



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Our proposal to deliver a value-driven roadmap in 100 days

MONTH 1 | MONTH 2 | MONTH 3 | MONTH 4 | MONTH 5

E2E VALUE MEASUREMENT and TRANSFORMATION

Kick Off — Steerco — wrap-up and POC scope validation — Integrated Architecture — WP3: Value Measurement and Draft Roadmap

Governance Set-Up

Support & Facilitate Governance Execution

1 AS-IS CAPABILITIES ANALYSIS, RISK ANALYSIS, ROI ASSESSEMENT

Interviews
- Management Interviews
- Focus Local Interviews
- Tactical Interviews

As-is Analysis
- System Engineering Processes
- Simulation Capability
- Mfg. Def. & Quality Inspections
- 3d Models Info

- ROI Analysis
- Planning for MVPs
- As Is Scan synthesis
- Risk Assessment

2 TO BE ARCHITECTURE, MVP SCOPE VALIDATION

Workshops
- Architecture sessions
- MVP scope validation
- Roadmap draft

- Platform Architecture Draft
- Detailed Value Matrix V1
- Integrated Use Cases
- Risk Assessment

3 E2E VALUE PILOT DELIVERY AND ROADMAP VALIDATION

Workshops
- Awareness sessions
- MVP validation
- ROI analysis
- Capability validation
- Roadmap validation

MVPs Development (MBSE, MBE, Real Time enablers, 3D Simulations, Ontology, Predictive simulations)

- MVP Delivery
- Draft Roadmap Validation
- NPV analysis
- Risk Assessment Update

4 ROADMAP AND VALUE ANALYSIS DELIVERY

Workshops
- Roadmap validation

- Roadmap
- NPV analysis
- High level design
- Action Plan validation

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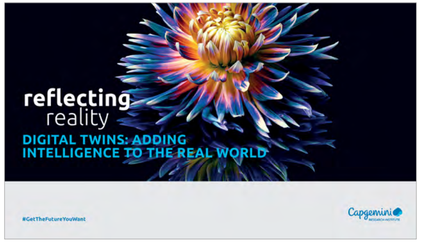

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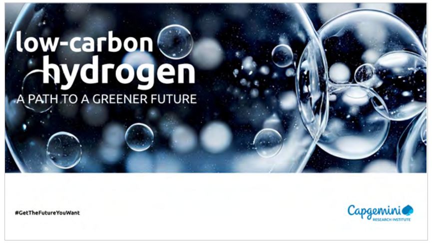

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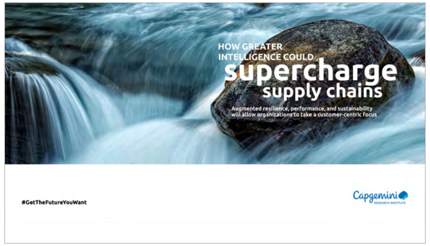

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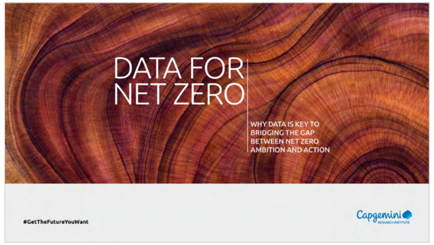

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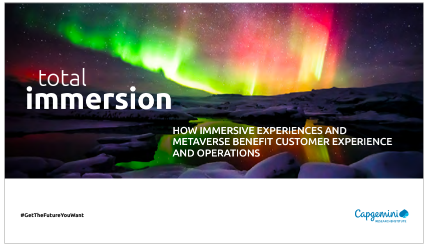

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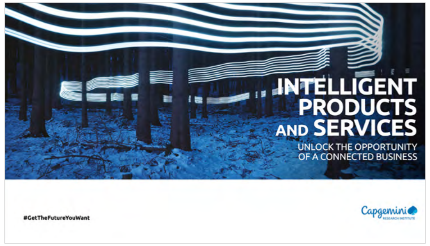

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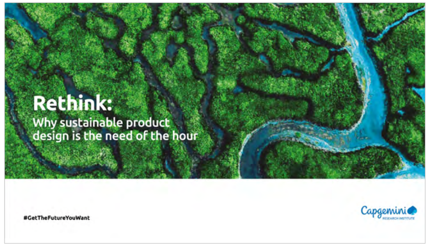

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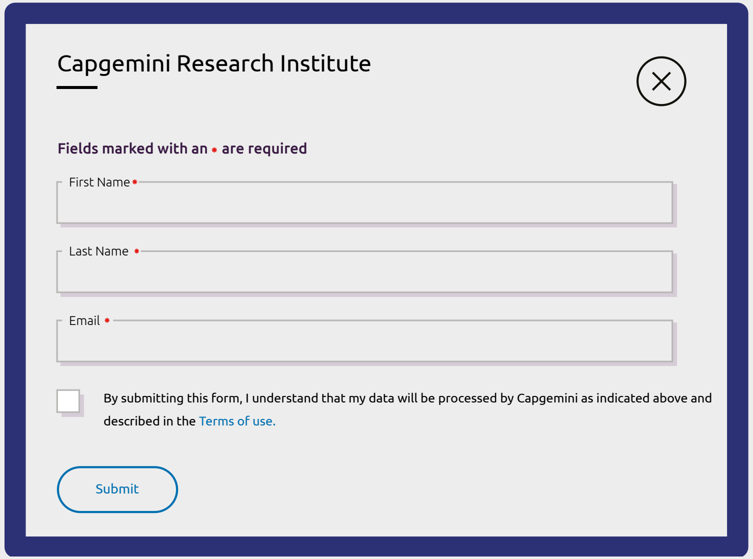
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