EXECUTIVE BRIEFING

Digital twins in the aerospace sector

Maturity model, practices and opportunities

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OMMS on-body therapeutic manufacture

Engineering and Physical Sciences Research Council

EXECUTIVE SUMMARY

Digital twins are increasingly regarded as key components of digital transformation, particularly in asset-intensive sectors such as aerospace. As ‘living’ models that mirror the properties and actions of a physical entity, they have the potential to unlock new and innovative value propositions that can help companies achieve sustainable competitive advantage. However, in spite of all the attention they are currently receiving, little has been published that shows how digital twins are being adopted and used in practice. This is the first study to explore the progress made to date by commercial aircraft original equipment manufacturers (OEMs). In addition, it provides a Digital Twin Maturity Model to guide OEMs and their suppliers as they aim to maximise the technology’s value to their customers and themselves.

By collating and analysing the perspectives of 30 industry experts from 13 different commercial aerospace OEMs, we explore: (1) the maturity of digital twin implementations in commercial aerospace OEMs, (2) the value and benefits derived from digital twins, (3) enablers and challenges in implementing digital twins, and (4) the outlook for their implementation in the sector.

Maturity across the sector

We used 10 dimensions to assess the maturity of digital twin implementations in each company. The results show significant variation in maturity levels across the different dimensions, with no clear front-runners emerging. We note that to date only 15 per cent of companies have deployed their digital twins commercially, that most are confined to a single lifecycle stage, and that half of the sector has limited access to vital operational data, with a quarter of companies having no access whatsoever.

The value of the digital twins

We investigate the value of digital twins from two perspectives: value for the customer and value for the OEM. Key benefits for the customer are less asset downtime and faster time-to-market as a result of their involvement in the product design process and digital testing. For the OEMs themselves, the main business benefits are derived from inventory prediction and lower design costs. Interestingly, we found that few companies are systematically measuring the current and future benefits of the digital twin.

Enablers and barriers

A clear consensus emerged as to the success factors needed for digital twin implementation: a shared vision of the objectives, frequent communication within and across departments and the right set of digital and data skills in the workforce. The importance of partnerships is also highlighted by almost all companies, reflecting both the need to collaborate with specialists to provide the best possible solutions and for gaining access to data. The most critical barriers to implementation are seen as: resistance to change within the company, an inability to develop a convincing business case and lack of access to data.

The future

We expect jet engine OEMs and aircraft OEMs to follow different paths. The former will focus on improving the modelling scope and analytical capability of their digital twins, while the latter will focus on establishing strong partnerships and collaborations.

Digital twins today

Over the past decade, manufacturing has been undergoing a significant and sustained transformation, thanks to advances in digital technologies. A recent industry report[1], values the total current digital transformation market at $248 billion. Digital twins – near real-time, whole-life digital replicas of physical assets – have become a key component of digitalisation strategies, particularly for sectors such as aerospace.

New opportunities

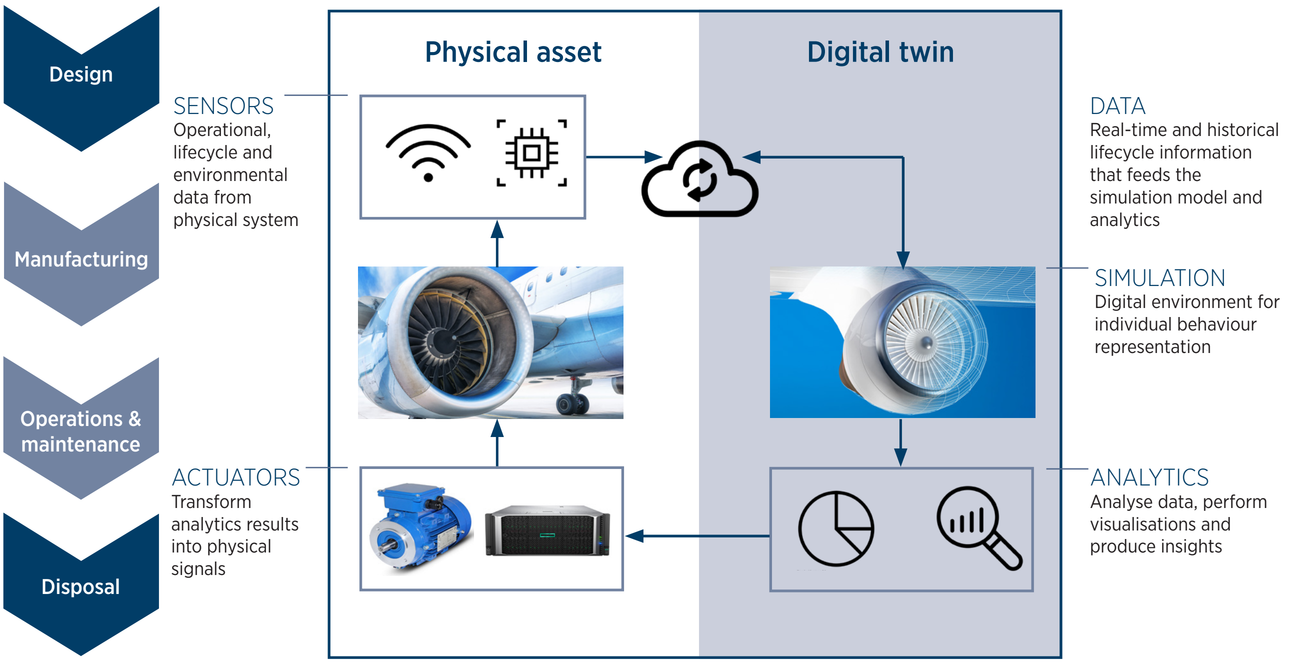
By providing this near real-time view of assets and processes throughout their life - from design to disposal - digital twins unlock new opportunities. The continuous insights they provide can, for example, improve the design of products and services, enabling a shift from reactive to predictive services and supporting the development of increasingly personalised services. They help to reduce time to market of new products and services and can underpin business model innovation. They also dramatically speed up communication and have an important role to play in training both employees and customers.

Many organisations recognise the potential for digital twin technology and are investing accordingly. Gartner valued the digital twin market at $3.1 billion in 2020 and projects growth of up to $48.2 billion by 2025. Digital twin and software providers such as Siemens, SAP, Microsoft and IBM have been fighting for market share in this rapidly growing field for the last four years[2].

Digital twins are already having a positive impact in industries such as renewables, with GE's 'digital wind farm' responsible for 20 per cent efficiency gains by enabling near real-time modelling, analysis and optimisation using its wind turbine twins.

However, in spite of a widespread belief in the technology's potential, there is little available evidence about how it is being deployed in practice, particularly in relation to products.

This report explores the deployment of digital twins in the commercial aerospace sector, to help firms understand how the technology is currently being used, how they compare with their competitors and what further opportunities they can realise in the future.



The concept of a digital twin. Adapted from: Viola, J. and Chen, Y., 2020. Digital Twin Enabled Smart Control Engineering as an Industrial AI: A New Framework and A Case Study. arXiv preprint arXiv:2007.03677

Digital twins maturity model for aerospace

We surveyed OEMs in the commercial aerospace sector, interviewing three employees at each firm, one with a management, one with an IT and one with a technical background. In total, we carried out 30 interviews with seven aircraft manufacturers and six jet engine manufacturers.

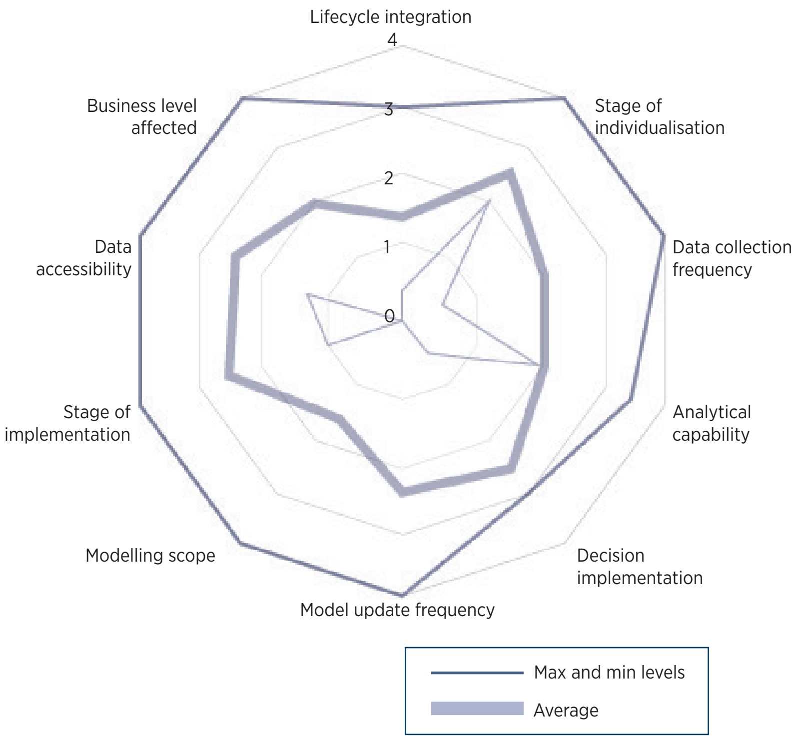
We developed a maturity model to guide our interviews and to help us understand how advanced each firm is in terms of its digital twin implementation and impact.

DIMENSIONS	Level 1	Level 2	Level 3	Level 4
Analytical capability	**Monitoring** Describing and analysing what happened	**Diagnostics** Understanding why it happened	**Prediction** Predicting what will happen	**Prescription** Prescribes ways to make it happen
Model update frequency	**Weeks** Frequency ≥ 1 week	**Days** Frequency < 1 week	**Hours** Frequency < 1 day	**Minutes** Frequency < 1 hour
Data collection frequency	**Demand-based** Flight incident-driven	**Flight history** Flight history data sent bundled after touchdown	**In-flight data** Continuous data sent at intervals	**Real-time** Continuous data with negligible latency
Modelling scope	**Parts** Individual parts	**Subsystems** Self-contained for specific purpose	**Complete product** Complete jet engine or aircraft	**Product environment** Modelling goes beyond individual product
Decision implementation	**No consideration of DT data** DT data not used for decision-making	**Human in the loop** DT input triggers human action on product	**Hybrid** Combination of Level 2 and 4	**Automated connection** DT can act directly on product
Lifecycle integration	**Single stage** DT integrated in one lifecycle stage	**Two stages** DT integrated in two lifecycle stages	**Three stages** DT integrated in three lifecycle stages	**Full integration** DT integrated along whole lifecycle
Stage of DT individualisation	**As-maintained** DT updated only when product is in OEM's workshop	**As-operated** DT continuously updated with operational data	**As-built** DT updated with assembly data	**As-manufactured** Manufacturing data down to tail number
Business level affected	**Process** Change of OEM's processes due to DT usage	**Product** Product adjusted due to DT implementation	**Business model** DT causes change in OEM's business model	**New business model** DT bring new solution-based models
Operational data accessibility	**Access in progress** Contracts being negotiated	**Restricted access** Contractual access secured	**Full access** Co-owner of the data	**Sole ownership** OEM is sole owner of data
Stage of implementation	**Conceptual** Until proof-of-concept is conducted	**Development** Until prototype trials are conducted	**Deployment** DT complete and qualified	**Deployed** Commercial success in operational environment

Maturity levels across the sector

We identified 10 dimensions of digital twin maturity. Each OEM was assessed against five levels of maturity. If firms were between levels, they were given a transition score such as 2.5.

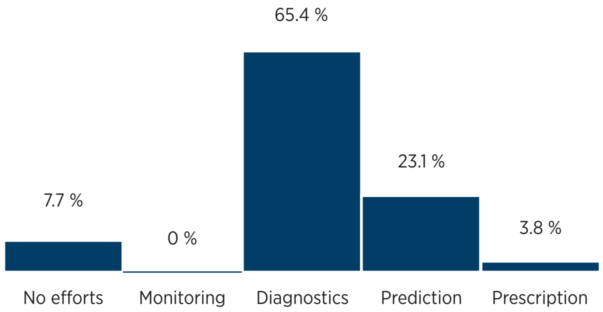
The spider web (right) illustrates the overall maturity assessment, the average maturity for each dimension and a corresponding minimum and maximum value. It clearly demonstrates that there are significant gaps between the industry leaders and laggards for each dimension.



Key findings for each dimension

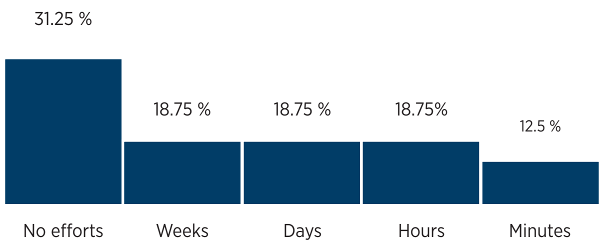
1. Analytical capability

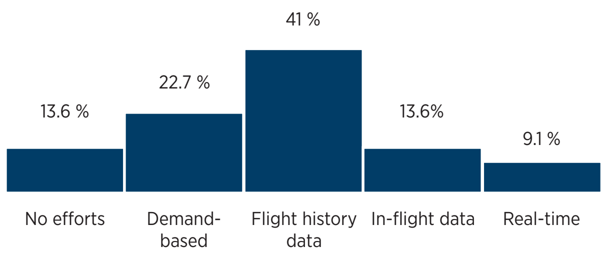
Almost 88 per cent of the OEMs are using their digital twins' diagnostic and predictive capabilities but only a small percentage of twins are currently capable of 'prescription'. In other words, the majority of digital twins are not yet able to decide what actions need to be taken and automatically execute them. This suggests that while discussion of both prediction and prescription is common in the academic literature, industry is not yet there. A possible explanation could be a lack of access to necessary operational data.



2. Model update frequency

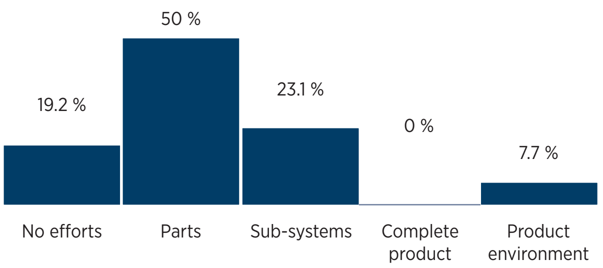
This was an area in which significant progress is still to be made with almost one third of OEMs not yet updating the model at all. Again, limited access to operational data is likely to be a factor.





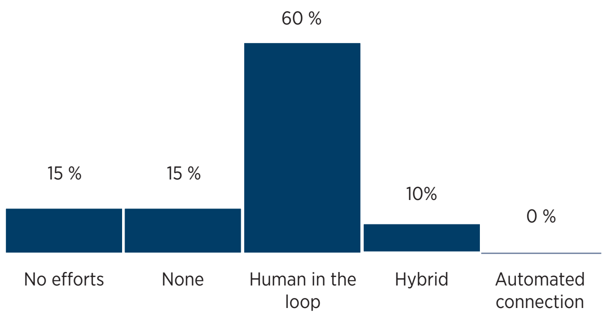
3. Data collection frequency

OEMs reports that only 41 per cent of the data is preserved as flight history data, whereas 13.6 per cent of data is in-flight data and only 9.1 per cent of data is real-time data. The majority of flight data is sent as a bundle after touchdown. Current opportunities focus on increase the real-time data communication.



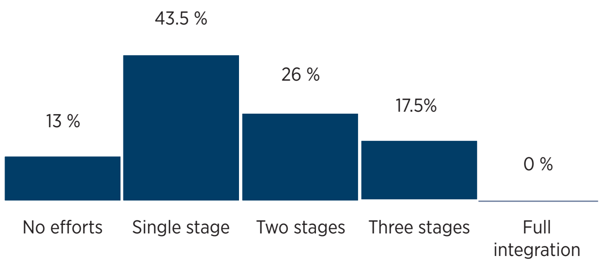
4. Modelling scope

Digital twins are still mostly being used to model parts rather than whole assets, with firm choosing to focus on critical components such as turbine fan blades. Only a relatively small number of OEMs are venturing into sub-system-level modelling. Modelling of digital twins depends to a great extent on the accessibility of data to build, test and simulate models.



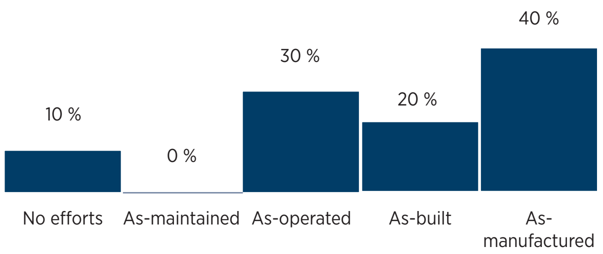
5. Decision implementation

The vision for a digital twin is that it will implement its decisions automatically on the physical twin. In reality, this is still mainly done by a human (a technician, for example), which is not surprising in a security-conscious industry.



6. Lifecycle integration

Almost half of the OEMs currently use a digital twin for a single lifecycle stage, indicating that there is some way to go before the vision of 'cradle to grave' integration becomes a reality.

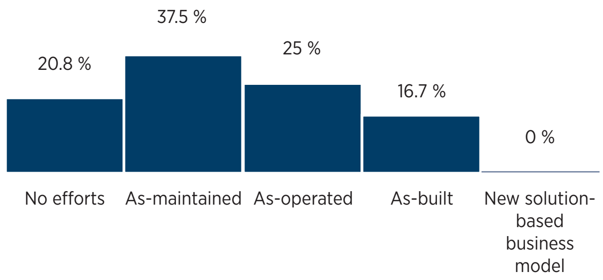


7. Stage of digital twin individualisation

The OEMs are relatively mature in this dimension with many already integrating as-manufactured data and including, for example, geometric variations caused by environmental variations during manufacturing. It is unclear why OEMs have made such good progress in this dimension of maturity, but less in modelling scope and model update frequency.

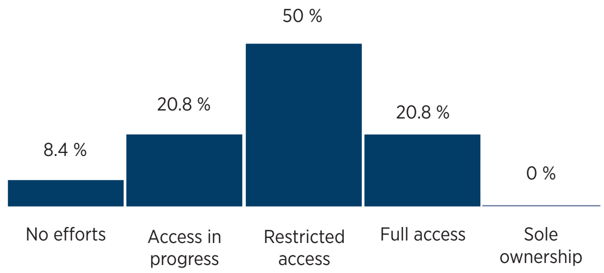
8. Business level affected

One in six OEMs report that they are changing their business model as a result of digital twin implementation, with some employing a Digital Twin Business Modelling Team and another stating: “The digital twin is coupled and deeply integrated into our business model”. However, the main focus of activity is still at the process level, where the digital twin enables improvements to existing processes such as maintenance scheduling.



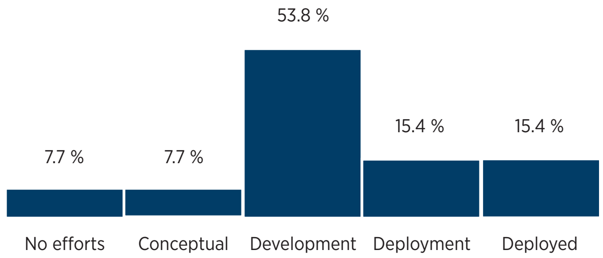
9. Operational data accessibility

This is a critical dimension and one that has been neglected in the literature to date. If an OEM sells a physical product but continues to operate the digital twin, it will need access to the operational data from the asset owner. However, a quarter of the industry currently has no access to operational data and half of the industry has only limited access. This limitation may also affect other dimensions and prevent OEMs from realising the full potential of technical progressions such as prescriptive behaviours.



10. Stage of implementation

The vast majority of digital twins remain in the development phase, with only 15 per cent of the OEMs having commercially deployed their digital twin.



Credit: iStock: frankpeters

Generating value from digital twins

As well as assessing the current maturity of digital twin implementations, we also explored the value proposition underpinning it and the perceived benefits to the OEMs themselves and to their customers.

VALUE FOR THE OEMS

For the OEMs themselves, being better able to predict inventory – and hence cash flow – were considered to be the two most important benefits of digital twins. It is interesting that prediction is ranked so highly but only a quarter of the OEMs have developed predictive capabilities.

Other significant benefits were reducing design costs and extending their products' capabilities. These are both closely related to customer benefits, corresponding to accelerating time-to-market and individualisation for customers.

In general - and unsurprisingly - there is a strong relationship between the internal and external benefits deriving from digital twins, as they affect the complete value chain of the physical product, and hence all the companies involved.

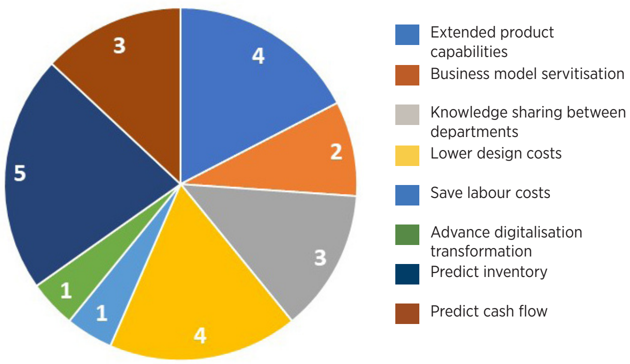
It is more surprising to note that only a few OEMs are quantitatively measuring such benefits. Those that are, are doing so partially using, for example, a black box approach or by tracking savings achieved during operations. No interviewee mentioned a complete financial overview of costs, savings and additional revenue generated by a digital twin.

One of the key enablers and an important aspect of a digital twin implementation is "having a clear business case" (see next section). However, this perception seems to be at odds with the almost universal lack of emphasis on identifying and measuring the benefits of digital twins.

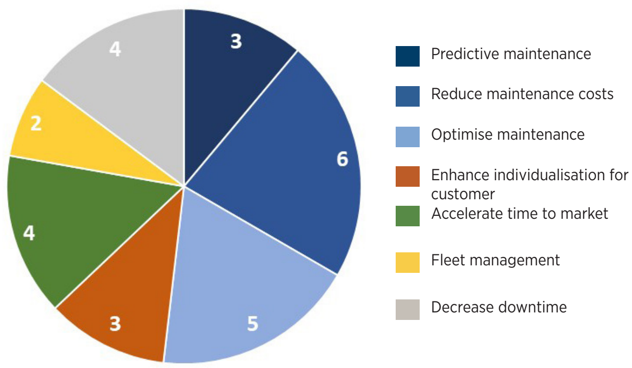
VALUE FOR CUSTOMERS

The OEMs identified seven different benefits digital twins can provide their customers:

- Reducing the costs of maintenance, optimising the maintenance schedule and reducing the amount of downtime were considered to be the main benefits.
- Another key benefit was accelerating the time-to-market. Digital twins, for example, make it possible to speed up the design process by analysing usage data from old designs, replacing time and cost-intensive testing with virtual simulations and enabling more rapid certification thanks to digital testing.



Benefits to the OEMs



Benefits to customers

"Optimisation of engine repair cycles and fuel consumption in respect to air currents and landing procedures.

"Knowing more in advance when parts are going to fail especially for off-the-shelf-parts which have a lead time of sometimes over six months.

"The digital twin allows us to include customers early in the product design to more effectively meet their needs.

"Making assets as available as possible ... enables predicting bearing failure in advance to be able to reschedule flight and crew.

It's new for everyone. For the suppliers, for the customers, for us, for the partners ...It's a whole different method of communication and working.

Implementing digital twins

SUCCESS FACTORS

The main enablers that were highlighted by most OEMs are:

1. Clear vision

Having a clear vision of what the digital twin should achieve is vital. Developing a compelling business case with success measures is an important mechanism for achieving alignment across the company.

2. Good internal communication

Clear and frequent communication within and across departments is also important. This can be achieved by establishing a framework for communication between multidisciplinary teams across different departments in the company. This is essential for overcoming resistance to the use of digital technologies and for ensuring effective coordination of activities and alignment in digital twin service operations.

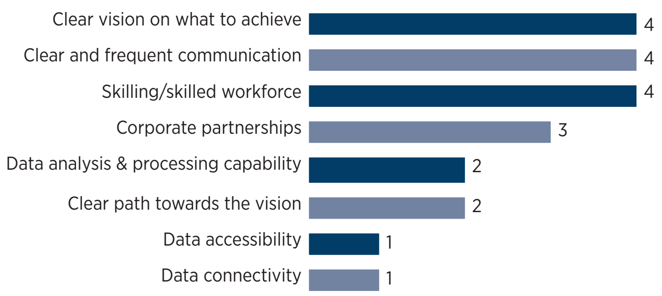
3. Skills

Firms need to have the right set of digital and data skills in place in order to maximise the value of digital twins.

4. Partnerships

Partnerships are also seen to be an important enabler, whether with software providers, establishing a start-up within the company or partnering with other airlines. These partnerships are key for two reasons: working with specialists to achieve the best possible solutions AND for ensuring access to data.

Technical capabilities for data analysis, connectivity and processing are also important. Being able to measure data accessibility, connectivity and reliability is critical to assessing the mean time before failure (MTBF), as well as identifying how often the asset losses connectivity with the ground. Furthermore, ensuring cloud security is key; achieving cloud data security as well as managing the transition to cloud-based services in a robust and secure way was frequently mentioned in this context.



CHALLENGES

Three challenges were considered to be most significant:

1. Resistance to change

This was by far the most common concern, with interviewees describing resistance to the technology both from employees who do not see the value it offers and from the aerospace sector as a whole. Aerospace is a complex and heavily regulated industry, in which new processes are developed over many years making it difficult to adopt innovations swiftly.

2. Developing a convincing business case for the DT

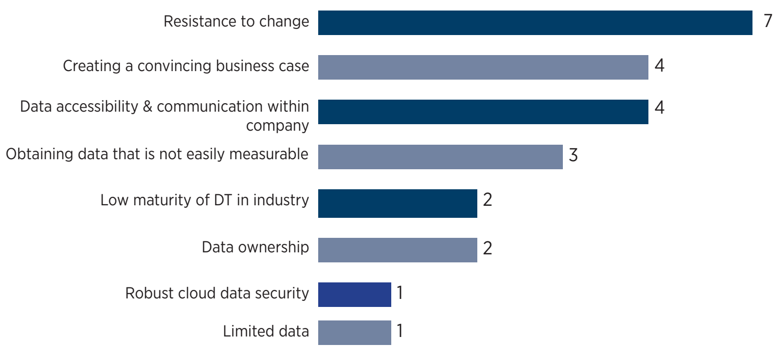
This reinforces the message which emerged from our discussion of success factors: that you need a clear vision of what you want to achieve.

The digital twin benefits are based on forecasts and assumptions...In engineering you need to justify a capital investment...in this case it is not possible because it is a new market.

The biggest barrier is justifying the Digital Twin's value. You get around by showing hypothetical use cases and what you can get out of them.

3. Data accessibility

There are multiple challenges relating to access both to external data and to data within the company. For example, one department may gain access rights to external data but other departments are not covered by the contract agreement and hence cannot access it. This highlights the critical role contractual agreements regarding data accessibility play in being able to implement and exploit the digital twin to its full potential. There are two key takeaways here: you need to have access as a company to operational data and you must be able to share that data across departments.



Conclusion: looking to the future

This report has set out to show the progress OEMs have made on their digital twin journeys to date and to recognise some of the challenges and opportunities that lie ahead. Each of the companies we studied possesses strengths in a particular set of digital twin dimensions. Their competitive advantage could be secured by making the right choice about where to focus their energies in the future.

Engine manufacturers will have a very different agenda from aircraft manufacturers with the former focused on improving the modelling scope and the analytical capability of their digital twins by incorporating AI or information from predecessor assets. Aircraft manufacturers, on the other hand, will put collaborations and partnerships at the top of their agendas in order to manage and unlock the value from their digital twins.

We observe that digital twins are already delivering significant internal and external value in spite of their relative lack of maturity, which means that further benefits can be expected to accrue as companies continue to develop the technology. The main sources of value currently relate to predictive analytics, but some companies are also diversifying their business portfolio by exploring new industries to serve with the insights obtained through their digital twins.

The principal challenges in implementing digital twins relate to data accessibility both outside and within the company, highlighting the importance of establishing close relationships with customers and drafting contracts that enable company-wide access to data. Other challenges OEMs need to address if they are to reap the rewards of the technology include being able to make a convincing business case for it, upskilling the workforce and convincing it of the benefits of digital twins.

These challenges go far beyond the technical. The lack of a data-driven culture is a major issue to which companies have to pay particular attention in order to foster a motivated and skilled workforce. Being able to strike a balance between the more experienced employees who rely on intuition and younger, data-driven employees who lack field experience will be of paramount importance. Data communication between people and software is also critical as is moving towards a different philosophy where being able to secure data access across the company while ensuring IP is protected is key. The physical models exist. Bringing them to life will involve much more than solving technical issues.

This report has highlighted that successful digital twin implementations require efforts that go far beyond the technical. They are a multidisciplinary endeavour that crosses company boundaries. Therefore, they require wholesale cultural changes within the company and throughout its ecosystem, with a shift towards digital and analytical literacy, as well as data/information sharing. Those companies that can truly leverage systems-thinking and nurture stakeholder relationships will be well positioned to harness the potential of digital twin-enabled offerings.

Further reading

Digital transformation market size, GrandReview Research (2020)

Gómez-Medina F. (2020). "Designing Better Products by Leveraging Digital Twins in the Aircraft Engine Manufacturing Industry". First year PhD report. University of Cambridge.

Martínez, V. (2017). "The role of digital twins in services business models". ISSIP-NSF Conference on Industry-University Collaborations for Smart Service Systems. San Francisco, CA. US 29th March

Gartner Survey Reveals Digital Twins Are Entering Mainstream Use (2019)

Digital Twin Market Report, MarketsandMarkets (2020)

Gómez-Medina F., Wollermann-Umpierrez, A., Martínez, V., Fromm, H. (2021). "An Analysis of Digital Twin Implementations in Commercial Aerospace OEMs". Working paper.

Gómez-Medina F., Wollermann-Umpierrez, A., Martínez, V., Fromm, H. (2021). "A Maturity Model for Digital Twin Implementations in the Commercial Aerospace OEM Industry". ICITM 2021 proceedings. ISBN: 978-1-7281-4306-4

Davenport, Thomas H., Harris, Jeanne G. (2007). "Competing on Analytics: The New Science of Winning". 1st ed.: Harvard Business Review Press.

Gartner: Elliott, Timo (2013): Digital Business & Business Analytics. #GartnerBI: Analytics Moves To The Core

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Ashish Gupta, CVP and Head of EMEA, HCL Technologies

"CEMEX has started its journey to design new services focusing on improving our customers' experience. The Design Lab Services was launched to research, diffuse and implement new approaches and best practices for service design. We are also committed to collaborating with the best universities and experts around the world on applied research and innovation projects to get prepared for the digital revolution."

Martin Adolfo Herrera Salado, Digital Enablement, Business Consulting Services, CEMEX

"One of the key things about the Alliance is the non-competitive nature of the partners within it. That allows us to move away from some of the more traditional IP and confidentiality rules, to openly share our challenges, dig beneath the surface of some of the hype about digital and get into the nuts and bolts about how we really deliver it and the challenges we all face.'

Caroline Burstall, Supply Chain Manager For Industrial Power Systems, Caterpillar

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