Challenges of Digitalisation in the Aerospace and Aviation Sectors

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March 2018
Series No. CDBB_REP_002
DOI: https://doi.org/10.17863/CAM.26276

UNIVERSITY OF CAMBRIDGE

This is a working paper, published in the CDBB publication series.

Acknowledgements:
This research was funded by the Centre for Digital Built Britain (CDBB). www.cdbb.cam.ac.uk

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Introduction

Building on the challenges highlighted in Report 2.1, this report describes digital transformation in aerospace and aviation, and identifies some challenges that are likely to have parallels with the architecture, engineering and construction (AEC) sector.

There are several reasons that this report includes aviation as well as aerospace. First, the literature overlaps; some sources discuss "defence and aerospace", some discuss "aviation and travel" and some use aerospace and aviation as interchangeable terms. Second, according to a survey of 750 "decision-makers" representing 5 key industries (aviation, construction, manufacturing, service, and oil & gas), aviation most strongly self-identifies as having a high level of digital maturity, with 44% saying that the industry is either digitally enhanced or fully optimised (IFS, 2017).[1] The aviation sector is a leader in information management and therefore a priority for this series of reports. Finally, aviation provides a view into how data can transform customer experience of services, a factor that is missing from many other sectors considering digitalisation.

This report begins with a discussion of DRIVERS AND INNOVATIONS in these sectors, focusing on digital twin technology and Internet-of-Things (IoT). As with the previous report, several challenges have been identified that may provide some forewarning to the AEC sector as it moves into digital operation and integration. DATA CHALLENGES, such as interoperability in systems-of-systems, pose the biggest technical challenge to both sectors, followed by the SECURITY of those systems, where the risks posed by a breach are severe. The human factors discussed in the previous report are now separated into HUMAN FACTORS IN ENTERPRISES such as recruitment and change management, and SOCIAL OUTCOMES such as customer engagement. Finally, the ROLE OF REGULATION in digitalisation and the INVESTMENT challenges facing these sectors are considered. The report concludes with an OVERVIEW OF THE LITERATURE, including a bibliometric review.

Key recommendations

The key recommendations arising from this report are as follows:

- Interoperability requires a suite of solutions including data and hardware standards, semantic software and cognitive systems
- Invest in agile platforms that can easily and cheaply be reconfigured or upgraded when needed
- Outsource technical solutions by leveraging partnerships with data-as-a-service businesses
- As a sector, develop regulatory frameworks and standards for hardware and data interoperability

[1] Respondents from the construction industry rated themselves second highest, with 39% considering themselves at an advanced level of digital maturity. These are based on self-reporting, which may mean that less digitally mature sectors rate themselves more highly due to lack of knowledge.

- Engage in constant monitoring, including transparent Machine Learning systems
- Build response policies to minimise damage during breaches
- Share knowledge throughout the sector in order to raise the security level throughout
- Agree on cybersecurity standards and responses as an organisation and as a sector
- Involve staff in cybersecurity through training and risk assessment
- Use technology to assist, not replace, human security personnel
- Ensure that digitalisation and automation support human workers rather than replacing them
- Focus on succession planning and development of current staff so that digital champions end up in leadership positions
- Transition the skills of the workforce to digital through training existing employees and engaging with the education sector to develop the needed skills
- Refrain from either clumping all digital experts together or spreading them thinly through the company
- Build agile, innovation-focused organisational structures
- Prioritise human experience and trust from design and implementation to iteration
- Source data from a more representative range of people to avoid biased algorithms
- Inform customers of how you will use their data at the point of capture and foster a culture of transparency
- Capture, analyse and value qualitative data that tell individual stories about how technology is or is not making people's lives better
- Establish frameworks for the appropriate use of data in consultation with industry and the public, including policies, standards and legislation
- Collaboration between government, industry and public representation will ensure that data regulation serves everyone's best interests
- Consider data protection not as an afterthought but as a core principle of the sector, and recruit people who will keep data protection and management standards and regulations at the forefront
- Centre digital projects around empowered digital leaders and flexible teams that will focus on producing minimum viable products
- Engage in systems thinking
- Set targets for cost savings, operational efficiency, revenue growth and innovation, and monitor results
- Invest ahead of the business case
- Be strategic about when to develop digital technology and when to go with ready-made, taking advantage of strategic partnerships
- Focus on a smaller number of high-value digital initiatives

Drivers and Innovations in Aerospace and Aviation

> *"'The highly competitive nature of the aviation industry, together with its rapid adoption rate of new technologies such as predictive maintenance and 3D printing for spare part manufacturing, are key drivers of its successful digitalization.'"* - Anthony Bourne, IFS VP of global industry solutions (IFS, 2017)

Aerospace and aviation represent a level of digital maturity beyond either construction or oil and gas (O&G), and both excel in different aspects. Both the aerospace and aviation sectors are exploring the benefits of digitalisation on operational efficiency and cost effectiveness through IoT, predictive analytics and digital twin technologies.

Both sectors also have a mandate to innovate. In aerospace, there is the need for global communication infrastructure and the continued exploration of the cosmos driving information management innovations and the closely related defence sector relies on information to maintain global security. Aviation, as a highly competitive sector that relies on data sharing partnerships to facilitate a seamless journey for passengers, is looking at the role of IoT as a way of curating customer experiences and gaining a competitive edge, while ensuring the travel experience is safe for passengers and their data. For the purposes of translating suggestions that might be useful in the AEC sector, aerospace has a stronger innovative focus in design, building and maintenance, while aviation is generally more innovative with integrating data.

Developments in the digitalisation of the aerospace sector mirror those in AEC. Boeing designed the 777 using the digital tools that were available in the 1990s, along the lines of CAD, while the Airbus A350 XWB was designed collaboratively using a 3D digital model, in parallel with Level 1 and Level 2 BIM. Now, however, digital technology is impacting "every aspect of the industry value chain: from passenger experience in the seat to airline operations and from design and manufacturing to service and support." (Accenture, 2016)

Aerospace faces challenges of maintaining and communicating with assets in remote and difficult conditions, meaning that information about assets should be accessible and interoperable between teams. The sector also needs to consider a vast array of interdependent physical and digital systems, including weather, GIS data, material performance, temperature, life support and so on. The defence sector requires similar levels of technical specialisation and information logistics. Both sectors have a strong R&D stream working on digital projects from mining Twitter to improve accuracy of NASA's Global Precipitation Measurement (GPM) (Teng, 2017) to modelling vehicles as-built, allowing operators to perform predictive maintenance and "increase the reliability of the flying vehicle because of its ability to continuously monitor and mitigate degradation and anomalous events" (Glaessgen, 2012).

Key projects in development in this sector are digital twin technologies, data relay infrastructure (Reinhart, 2017) and remote manufacturing (Keys, 2017). Leaders include Airbus, who have set out a roadmap to using digital twin technology for predictive maintenance and operational enhancement (Bridgwater, 2017). They have also partnered with IBM Watson to help manage the volume of data generated during flight in order to help with maintenance and operation. Rolls Royce and Microsoft have partnered to deploy sensors in engines and manage the data using Cortana and Azure, while GE Aviation use Jasper IoT solution, both with the aim of "delivering real-time performance data." This allows them to, for example, perform aircraft maintenance before human mechanics might have noticed a problem, saving the airline the expense of unscheduled downtime. (Technavio, 2017) Meanwhile, Lockheed Martin "intends to create digital twins for almost everything—the products, processes, and tools" in order to have data for the whole life of a vehicle (Gutierrez & Khizhniak, 2017). FIGURE 1 outlines emerging digital technologies that may have a high impact on various external business challenges in the aerospace sector.

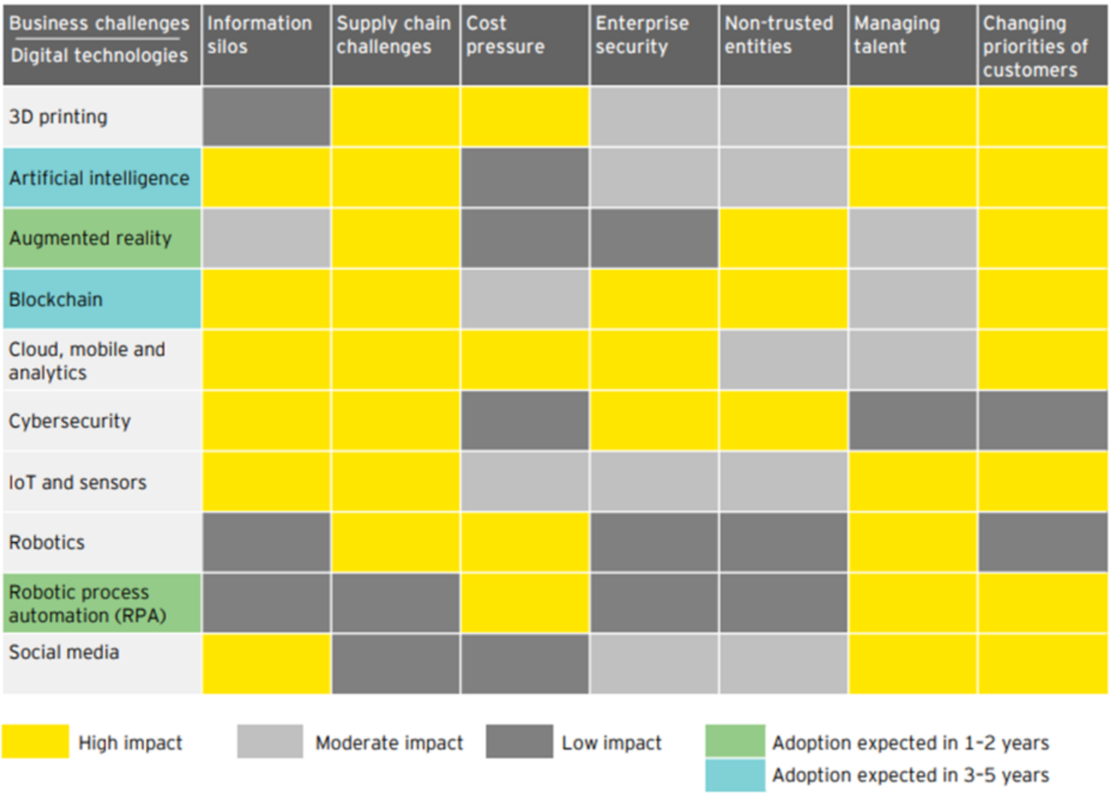

Figure 1 - How digital technologies will impact business challenges. Source: Maiti (2017). Used with permission.

Aviation faces a different set of challenges. Complex logistics for high-value assets are still a factor, but business-to-business and business-to-consumer commerce adds a different dimension of data to manage. A key challenge for service providers in this sector is in creating an environment that is intelligent enough to anticipate customer needs and curate a superior, seamless experience while not being invasive or insecure. This involves a huge amount of data from customers, airport and in-flight sensors and numerous vendors flowing between service providers who may be in competition with each other. Add to this the security concerns associated with travel hubs and the aviation sector has a serious IoT challenge that it is working on far ahead of other sectors.

Innovative projects are using sensors and user-generated data to build new IoT-driven business models, with airports as hubs of linked data interfacing with customers in a variety of ways.[2] London City Airport has used sensors and networked data to enhance customer experience, leading them to invest $24.46 million in an IoT framework focused on dealing with their increasing volume of passengers. Air France-KLM allow frequent flyer customers to track their own bags from their smartphone using RFID. (Technavio, 2017) Quantas have partnered with Umbel, a unified customer data platform, to create a data hub for individual preferences. “In-flight entertainment and services are already being personalized, as are real-time ticket booking and check-in processes. Qantas also

[2] Leaders include Toronto Pearson International Airport (Ontario, Canada), London Heathrow Airport (Hillingdon, UK), Singapore Changi Airport (Singapore), Hong Kong International Airport (Hong Kong), and McCarran International Airport (Nevada, US), all of whom have hosted “smart airport” pilot projects. (Technavio, 2017)

has a smartphone application with a personalized interface to streamline the day-of-travel experience for customers." (World Economic Forum & Accenture, 2017)

Drivers in both the aerospace and aviation sectors include the falling cost of sensors; rising demand for airliners; improved performance and cost efficiency; the growth of big data; and the demand for information infrastructure and analytics. Accenture (2016) points to an "urgency" to fully embrace digital capability and a digital coming of age for the aerospace and aviation sectors, but warns that businesses should be careful not to perform endless analytics without thinking about why they are gathering and analysing the data. As sectors transition from "'doing digital' to 'being digital'", as shown in FIGURE 2, digital literacy is therefore an essential foundation on which digital transformation should be based.

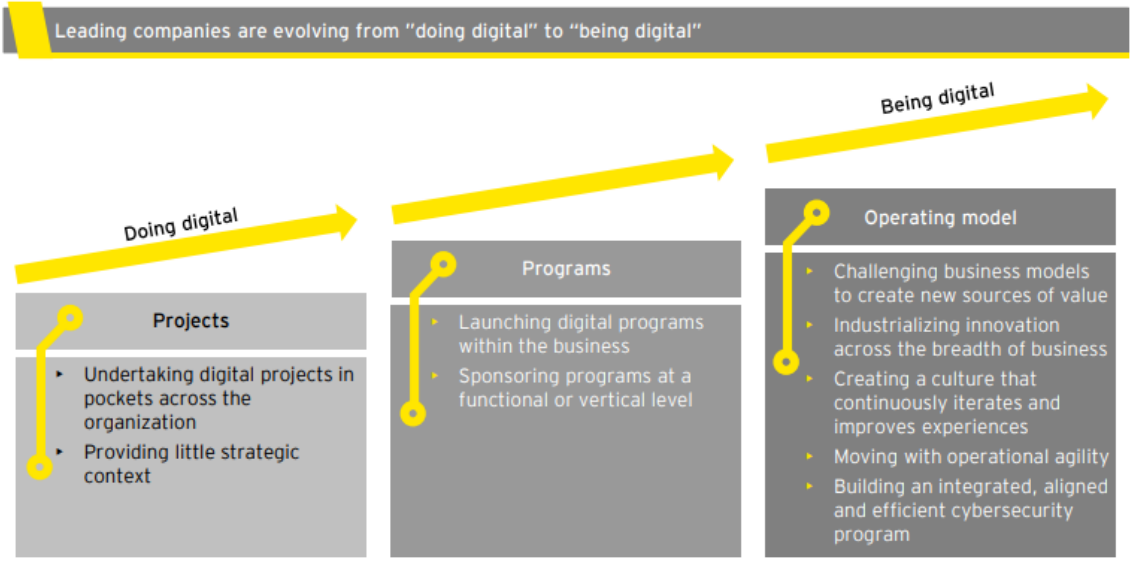

Figure 2 - An alternative digitisation wedge, from digital projects to digital operations. Source: Maiti (2017). Used with permission.

Challenges and Solutions

Challenge 1: Data Challenges

> *"Collaboration and data-sharing within the industry ecosystem will become more important and play a vital role in supporting initiatives that improve demand forecasting and asset optimization. As this data could be commercially sensitive, stakeholders might be hesitant to collaborate. Successful collaboration between ecosystem players will, however, bring huge benefits for both the industry itself and wider society (e.g. fewer emissions, reduced aircraft noise, cost savings), so regulators and governments should encourage the industry to create data-sharing platforms." (World Economic Forum & Accenture, 2017)*

Data availability and quality

Gathering, transmitting and managing data relies on physical infrastructure of sensors, servers and communication technology. Poor or non-existent ICT infrastructure can be a hindrance, whether in deep space, in-flight or in developing countries. The defence sector in particular faces a challenge in analysing data gathered in areas without adequate infrastructure (Namde, 2017). Setting it up is a big investment, but the price tag is gradually becoming more affordable as sensor technology becomes cheaper and broadband infrastructure begins to permeate the globe. However, the higher the volume of data, the greater the strain on information infrastructure.

When data are available, however, it does not mean that they are complete or reliable. Quality assurance is a crucial part of smart infrastructure and is a major technical and cultural challenge to overcome. Where decision-making systems require data from multiple agencies or hubs, there is an increased risk that those data will be incomplete, inconsistent or non-existent. Availability of data was a major hurdle for a pilot project at Brisbane Airport, where missing data would have invalidated the project. It was therefore "necessary to adjust data for every case where data are erroneous and incomplete, and sometimes use data from other regions (i.e. Perth, Melbourne and Sydney) where data is unavailable." (Baker & Mahmood, 2012)

Ensuring access to big data means creating infrastructure that doesn't yet exist in the form of much more robust repositories and the "development of architecture and meta data guidelines to support those repositories. There will also be a need to develop sufficient access/restriction controls." (Hale, 2017) Fortunately, various sectors are already working to develop this infrastructure, and AEC may be able to leverage existing expertise as opposed to reinventing the wheel.

Interoperability

As with the O&G sector, ensuring diverse, distributed data can be translated into compatible formats is a key technical challenge. In spacecraft design, for example, data from engineering, physics, climatology and so forth need to be relatable to each other despite differences in standards and formats (Hoppe et al., 2017). The variety of the data is not the only problem. Big data is also characterised by high volume and high velocity of growth, and the more data a sector is producing, the more difficult it is to extract valuable knowledge. According to Technavio (2017), "the aviation industry still requires the implementation of smart machine learning algorithms to generate value from the IoT technologies, which can derive insight from the sensor data and propose actions in real time." Interoperability, then, requires a suite of solutions including data and hardware standards, semantic software that can interpret between sectors and cognitive systems that can learn from the data.

Hale (2017) recommends that "approaches to implementing critical, enabling IT infrastructure capabilities must be flexible, reconfigurable, and updatable. Establish accessibility to, and interoperability among, disparate, heterogeneous tools, models, and other data sources for critical, enabling capabilities." This is easy to suggest, but much more difficult to accomplish amid the proliferation of tools, formats and standards. Existing digital infrastructure may need to be replaced at great cost, and individual enterprises may be reluctant to agree on a standard format.

Industry collaboration

Intra- and inter-industry data sharing may face barriers due to lack of willingness to collaborate. Baker & Mahmood (2012) observe that:

> *"Planning that might be optimal for a metropolitan region, arising from close coordination among these infrastructure and land policies may not benefit individual agencies, given their narrower scope and constituency. This is a fundamental conflict, and until there is a broader framework that subjects all of*

> *these institutions to pressure to align their interests with broader metropolitan objectives, it is not likely that implementing integrated planning will advance far, no matter what tools are used."*

Such pressure could come from policies and standards, or from a sector-wide consensus about issues that are important to tackle. Baker & Mahmood (2012) discuss the development of Planning Coordination Forums, "a forum for concerned agencies where they can discuss various policies as well as their implementing measures". As BIS warns, government-led standards are less likely to be successful than if the standards are shaped and agreed upon by the market (Department for Business, Innovation & Skills, 2016), pointing to the need for sector-wide agreement on standards and norms for data sharing.

In aviation, the complex data ownership structure has already led to necessary innovations in information sharing. While on the ground, aircraft and maintenance are usually the purview of airlines, but once in flight, "operations are controlled by the airspace operators like EUROCONTROL or Federal Aviation Administration (FAA)." The data generated in-flight is therefore transmitted to cloud-based storage, where they can be accessed in real-time by the necessary authorities. (Technavio, 2017) The necessity of data sharing has led this sector to develop the infrastructure and inter-agency agreements to support it.

Possible solutions

Model-based systems engineering (Hale, 2017), ontologies (Keller, 2016) and cloud computing (Bridgwater, 2017) have all been suggested as possible solutions to the technical challenges of big data, and there are scores of software platforms, apps, vendors and service providers that could be used to fit these needs. However, a fragmented market is unlikely to help businesses deal with the speed of obsolescence and the need for interoperability. Therefore, rather than focusing on technical solutions it may be more useful to think of a business model solution.

Data-as-a-service is a business model that enables sectors such as aerospace and aviation to outsource the technical knowledge to a specialist provider. For example, climate data analytics poses various technical challenges for NASA due to the enormous scale and fidelity needed. Transferring the data from store to store as different organisations need to access it is costly and time consuming. Instead, climate data providers have developed a service layer on top of cloud-based data storage that can then be an interface for other organisations to access and analyse the data. With data-as-a-service, the provider specialises in managing and analysing the data for organisations like NASA much more quickly (Schnase, 2014).

Similarly, defence logistics officials increasingly rely on strategic partnerships with IT specialists. The National Geospatial-intelligence Agency (NGA) uses geographic data from ArcGIS, hosted by Amazon Web Services Commercial Cloud Services (C2S), and other agencies collaborate with the likes of Boeing, Dell and Microsoft for digital logistics and supply chain management services. Engineers at Pratt & Whitney are working with IBM to visualise the data from the company's engines and extract better insights. This model also helps avoid costly investment in infrastructure that quickly goes out of date. (Howard, 2016)

The following suggestions have been drawn from the literature discussed in this section:

- Interoperability requires a suite of solutions including data and hardware standards, semantic software and cognitive systems
- Invest in agile platforms that can easily and cheaply be reconfigured or upgraded when needed
- Outsource technical solutions by leveraging partnerships with data-as-a-service businesses
- As a sector, develop regulatory frameworks and standards for hardware and data interoperability

Challenge 2: Security

> *"As identity management becomes increasingly digital, a collaborative effort towards boosting cybersecurity and protecting the privacy of traveller data will be crucial to maintaining customer trust and public safety. Digital technologies (e.g. biometrics such as facial recognition, IoT, crowd analytics and video monitoring via AI) will be used to create a ubiquitously secure environment." (World Economic Forum & Accenture, 2017)*

Security of data

Cybersecurity threats are likely to escalate in frequency and severity alongside spreading digitalisation. Bruno (2016) reports that "39% of A&D executives report the number of privacy and security breaches has doubled over the past two years." As dependence on mobile devices and networks for data transmission increases, so does the opportunity for information theft (Technavio, 2017).

The defence sector has been a leader in this area, developing standards for cyber security that contractors and subcontractors it works with are expected to follow. Standards were developed after "significant back-and-forth between the U.S. government and the defence contractor community", and have been adapted to fit the private sector as "a variety of organizations begin to address the complex issue of supply chain risk management as enterprises are increasingly cognizant of potentially vulnerable applications or data systems being used by their vendors" (American Institute of Aeronautics and Astronautics, 2018e). However, these standards are only of use if they have all of their "mechanisms and policy prescriptions engineered, in place, and well understood by management before the crisis strikes." (American Institute of Aeronautics and Astronautics, 2018d)

Machine Learning (ML) technology offers another way of addressing cybersecurity concerns as the volume and velocity of data increase. According to the American Institute of Aeronautics and Astronautics (2018b), "Organizations can waste as much as $1.3 million per year responding to 'inaccurate and erroneous intelligence' or 'chasing erroneous alerts,' … Better solutions are trained by using ML to analyse vast stores of human-labelled data so that it can find patterns within the noise." It can also intelligently control access to and protect classified data. (Hale, 2017)

Whatever technical solutions are implemented, humans remain the most vulnerable link in the security chain. Phishing and social engineering take little technical skill and can be the most effective way of accessing sensitive information. For example, a Russian hacking group targeted 87 people in aerospace and defence, and successfully accessed an unknown quantity of information about military technologies (American Institute of Aeronautics and Astronautics, 2018d). Therefore, security should be the job of everyone in organisations, not just IT. Training and education should help everyone identify phishing emails and learn how to reduce the risk of social engineering attacks, while every area of an enterprise should contribute to the risk assessment because of the different types of data they hold (American Institute of Aeronautics and Astronautics, 2018a).

Strangely, more openness may be a useful way of addressing cybersecurity threats, as data sharing throughout sectors is a useful way of ensuring that all stakeholders are aware of the latest threats and security developments. Convincing individual organizations to share data more widely, however, is a challenge, as is bringing new organisations into the fold of an existing arrangement. ISAOs, a product of a 2015 executive order as a way of promoting industry and government sharing, are "a less structured, more flexible institutional format, allowing any group of organizations to form a non-profit to enhance information sharing." (American Institute of Aeronautics and Astronautics, 2018c)

The ICT market has also developed open source and proprietary solutions that give security analysts a high degree of control, including:

> *"The ability to choose who they are sharing information with, exchange machine-readable indicators and other threat information, redact sensitive data that is not relevant to the threat being discussed, and encrypt sensitive communications about the data. … These platforms also allow the identity of the sharing entity to be anonymized, which may make organizations more likely to share." (American Institute of Aeronautics and Astronautics, 2018c)*

Sharing data is not a panacea, but may raise the overall level of security throughout a sector.

Balancing cybersecurity with national/global security

Few sectors are more conscious of national and global security than aerospace and aviation. In the case of defence, cybersecurity equates to national security as theft of defence data or disruption of communication could mean the loss of human lives. In aviation, holding and sharing data about passengers helps maintain global security, but in order to keep customers' trust the sector must ensure that they keep data secure throughout those processes. With IoT technology, aviation is holding more and more biometric and personally identifiable data about its customers, which in turn is helping to maintain global security, but constitutes a tempting target for theft.

In the case of the Aruba Happy Flow scheme, piloted by the governments of Aruba and the Netherlands along with KLM and Aruba Airport Security, trusted passengers need only show their passport once, and then are subsequently cleared using facial recognition including at check-in and boarding. This reduces the number of checkpoints where customers have to have their identity checked by a human. Rather than replacing security personnel with digital processes, however, technology should be used to empower human workers. "Security personnel will use data, new digital tools and smarter processes to manage security better while improving passenger flows through airports." (World Economic Forum & Accenture, 2017) This hybrid approach to security could be built into national infrastructure as well, with law enforcement and security personnel aided by digitally enhanced assets.

Possible solutions

The following suggestions have been drawn from the literature discussed in this section:

- Engage in constant monitoring, including transparent Machine Learning systems

- Build response policies to minimise damage during breaches
- Share knowledge throughout the sector in order to raise the security level throughout
- Agree on cybersecurity standards and responses as an organisation and as a sector
- Involve staff in cybersecurity through training and risk assessment
- Use technology to assist, not replace, human security personnel

Challenge 3: Human factors in enterprises

> *"'There is a digital illness in the back office of almost every airline carrier. The complexity that is inherited from the sixties is the main inhibitor here. Technology changes every day but humans are not changing fast enough – the problem is not in the technology.'"* - Pascal Buchner, Chief Information Officer, International Air Transport Association, Switzerland (World Economic Forum & Accenture, 2017)

Transformation of the workforce

As with O&G, recruitment is a challenge for the aerospace sector. According to Accenture (2016), in the U.S. 28% are at or near retirement and Bruno (2016) warns of engineering talent being pulled away from aerospace and defence careers by "more digitally advanced aerospace start-ups and Silicon Valley-oriented high-tech industries." This has led to a skills gap that is a potential barrier to digitalisation. An IFS survey (2017) addressed the issue of where the largest skills gaps could be seen throughout various sectors. Leading the responses were "business intelligence" with 40% and "cyber security" with 39%. Beyond skills gaps, among the top three barriers to digital transformation, leaders from various sectors pointed to "aversion to change" and the "absence of the right organizational and governance model".

Weak technical capabilities in the workforce can be addressed in several ways according to Baig et al. (2017). They recommend leveraging capability from digital partners and using third party services rather than in-house solutions, but warn that, "Companies should resist the urge to cast every decision about new technologies as a binary choice between developing a technology from scratch and buying it from a vendor. Instead, they should frame these decisions in terms of a development spectrum that ranges from proprietary one-off solutions, to open platforms that a network of developers can build on, to using algorithms created by a partner or even a customer."

Automation and digitalisation are likely to dramatically change the types of roles available in both aerospace and aviation. "About 25,000 [jobs] at airlines, an estimated 12,000 at airports and roughly 4,000 at aircraft manufacturers will be displaced by increased digitalization." This could be mitigated by the creation of potentially more than 650,000 digital jobs by 2025, but the change in the sector is likely to disproportionately affect workers who have not had the opportunity to train for this sort of work (World Economic Forum & Accenture, 2017). It is therefore crucial to train existing employees to move into digital roles in addition to educating future generations. A site manager at Airbus expressed the need for sectors exploring digitalisation to ensure that skills are available in the up and coming workforce:

> *"Businesses that address the issue of digitalisation head on can even expect to create more jobs – which means we have to start thinking now about how to secure the specialists we will need. Besides training the employees we already*

> *have, we have to ensure that the topic of digitalisation is explored in universities and in apprenticeships."* (Raveling, 2017)

To make the sector appealing to new talent, Ketzner & Cailliau (2017) report that the best performing companies are "establishing digital leadership positions and looking outside their organizations to fill new digital roles." Baig, Baptista, Coleman, & Roller (2017) point to the importance of organisational culture, noting that one industry leader "has set up a so-called digital factory in Paris to create technology products using agile development and other digital-native techniques". To create this kind of environment businesses should place digital teams in environments that are structured more like Silicon Valley firms, offer competitive salaries and understand the differences in value measurements between the sectors.

Resistance to change

Beyond skills gaps, leaders from various sectors pointed to "aversion to change" and the "absence of the right organizational and governance model" as barriers to digital transformation (IFS, 2017). Reluctance to change, therefore, may come from the management structure or from employees.

According to Abollado, Shehab, & Bamforth (2017), resistance among employees may come from the fear that their employers are using data to monitor and micro-manage them. Where employees fear that new technologies may be brought in to replace them, it is the responsibility of employers to ensure that "'the adoption of digital technologies empowers workers, enabling them to carry out their tasks better and more easily, more productively, and more ergonomically.'" (Raveling, 2017) That should be communicated clearly, including through training existing employees. Indeed, "more than 90 percent of manufacturing executives agreed that 'internal employee training and development programs' are the most effective in addressing the talent shortage among the workforce." (Deloitte, 2018)

Organisational structure

On the other hand, where resistance to change comes from the organisational structure itself, new business models may be needed. Baig et al. (2017) discuss the need to build a model that favours digital transformation and to put greater weight behind digital initiatives:

> *"Each digital initiative should be clearly assigned to a champion who has the clout within the organization to push it forward, such as a business-unit leader from a new acquisition or the original company, or a new digital executive. Initiative leaders should also be given the authority to make decisions and draw on the resources they need, even if that means pulling in staff from other functional groups, such as operations and engineering, or hiring additional technology talent."*

Possible solutions

The following suggestions have been drawn from the literature discussed in this section:

- Ensure that digitalisation and automation support human workers rather than replacing them
- Focus on succession planning and development of current staff so that digital champions end up in leadership positions
- Transition the skills of the workforce to digital through training existing employees and engaging with the education sector to develop the needed skills

- Refrain from either clumping all digital experts together or spreading them thinly through the company
- Build agile, innovation-focused organisational structures

Challenge 4: Social outcomes

> *"Travellers will experience seamless journeys tailored to their habits and preferences. Companies along the Aviation, Travel and Tourism industry journey will optimize customer experience by collecting and exchanging data, and continuously generating insights. In time, travel will become frictionless, blending seamlessly with other everyday activities." (World Economic Forum & Accenture, 2017)*

With the ubiquity of mobile devices the opportunity of communicating to - and gathering data from - airline customers is growing. According to Irvin & Schmid (2017), "Over 95% of passengers in the US are carrying at least one mobile device", leading to an unprecedented opportunity to monitor and understand customers. The challenge, then, is how best to leverage this data-rich environment for customer engagement and wellbeing without crossing the threshold into intrusiveness.

Customer engagement

IoT gives organisations an unparalleled opportunity to provide customers with a range of experiences including customised in-flight entertainment, perks and information (Technavio, 2017). Irvin & Schmid (2017) outline five dimensions of customer experience (CX) and highlight possible examples from a digitally enhanced airline journey:

> ***Engage me:*** *"Using beacons, NFC, or Wi-Fi airlines can greet passengers when they arrive at the terminal and offer special incentives for purchasing upgrades or early boarding based on real-time, situational data with customized messaging at via text or push notifications."*
>
> ***Empower me:*** *"Instead of a text message announcing a delayed flight, offer one click options for rebooking via a different city, an upgrade for taking a later flight, or continuing to share updates if elect not to change plans."*
>
> ***Hear me:*** *"Using RFID tracking you notify the passenger upon landing that their checked baggage is delayed and provide the itinerary of its delivery. Offer them options for services they need and let them communicate and feel in control."*
>
> ***Delight me:*** *"With the wealth of data about traveller's locations, tendencies, and preferences, airline loyalty programs can use apps to reward customers with surprises such as a discounted ride home or concert tickets at a destination."*
>
> ***Know me:*** *"Customer data can help fine-tune ancillary products so they're customized for each passenger and even that passenger's reason for traveling that day."*

A market report on technology in air travel conducted by Amadeus (2012) shows how every stage of the passenger journey can – and most likely will – be transformed by technology; from "bomb-sniffing" x-rays and airlines recognising when a passenger is stuck in traffic and taking the initiative to rebook the flight, to "unified communication from whole airport ecosystem through one channel and device." The report indicates that these technologies could be in routine use by 2025. Their vision of a technology and service ecosystem is lofty, but worthwhile:

> *"The long-term challenge is to evolve sustainable ecosystem models where airlines, airports, ground handlers, concessionaires and other key stakeholders work together, bearing an equitable share of the costs and receiving fair returns. This multi-level collaboration of ecosystem partners may stretch to shared ownership of the airport itself, so that goals are aligned, a more holistic approach can be taken to the sharing of revenues and profits, and an integrated seamless service can be delivered to the customer." Amadeus (2012)*

Engagement with customers need not be only in the form of using personal data to curate a service. Collaborative digital twin technology in combination with augmented or virtual reality empowers customers to have a voice in the early stages design of a physical asset, "Thereby minimizing the need for expensive late-stage design changes. For example, many leading A&D companies have recently built immersive centers in which customers can experience new product capabilities virtually and provide input into the designs. One leading A&D company reported that it captured a return on its investment in immersive centers within one year." (Ketzner & Cailliau, 2017)

Accessibility, representation and animal welfare

Beyond luxury experiences, access to technologically-enhanced experiences for customers with different abilities is a social justice concern. According to the Office of National Statistics, in 2015 a quarter of adults with disabilities in the UK had never used the internet, compared to around 10% of the overall population (Scope UK, 2016). This divide is not an inevitable part of a digital society but rather the result of design decisions that have excluded part of the population. Access to and confidence with using technology is a potential barrier to people benefitting from a digitally enhanced environment.

It is therefore promising that the aviation sector is considering how IoT can help everyone navigate their services more smoothly, as Technavio (2017) reports. "The fundamental principle of assistive technologies represents the development of a single system environment that can be used by everyone, i.e., not limiting it for the passengers with disabilities." For example, Apple's iBeacon protocol allows smartphones and tablets to communicate with beacons in the physical world. "iBeacon can emerge as one of the most useful approaches for guiding airline passengers (irrespective of their abilities) to the security gates or helping them acquire automatically printed boarding passes (through interactive kiosks) to avoid queuing." Outside the airport, technologies like Wayfindr, based on an open standard architecture, can help make whole cities more accessible for people with visual impairments and other disabilities. (Technavio, 2017)

If it is prioritised throughout the design and deployment, IoT systems can use real-time data and machine learning to provide more universally humane experiences rather than experiences that have been designed for some "average" or "ideal" persona. Evidence of this being done poorly is the recent revelation that data for facial recognition software were sampled from mostly white faces, meaning that the technology is disproportionately unable to recognise black and brown faces (Tucker, 2017). A bias toward a particular population in the underlying data means that the machine learning algorithms they feed will replicate that bias.

Jenner (2015) discusses how IoT can help monitor the wellbeing of human and animal passengers on flights. “Earlier this year, Delta Cargo launched a pet-tracking service on domestic flights as part of its GPS tracking services, allowing customers to monitor the humidity, light and temperature that their pet experiences, as well as the animal's location.” Intelligent systems on flights may soon be able to monitor hydration, tiredness and so on of human passengers and modify the cabin environment accordingly, or alert the crew. Digitalisation may also benefit the wider environmental impact of aviation, “contributing to a more sustainable industry footprint through innovations in manufacturing, smart assets and efficient resource use” (World Economic Forum & Accenture, 2017). These socially and environmentally beneficial outcomes should be built into the digitalisation process and not tacked on at a later date.

Trust

Even if different vendors and stakeholders can agree to share data for a smoother customer experience, that does not mean that customers will approve. A major challenge in adoption of IoT is the lack of trust people have in how their data will be used. As machine intelligence creates new ways of researching and analysing data, society may not always embrace these changes (Ambur, 2016). In the wake of the Cambridge Analytica scandal, public trust in organisations handling their personal data is likely to suffer (Lewis, 2018).

Navigating this barrier involves shifting business and information culture to one of greater openness, where individuals are empowered by the choice of how and where to share their data. According to Steve Singh, CEO of Concur Technologies, “’Customers will share personal data if there is a clear value proposition. If we are using that information in a way that is not transparent to that individual or very clearly just trying to monetize on that transaction – then customers will no longer share data.’” (World Economic Forum & Accenture, 2017) Quantas, for example, offers frequent flyer points as an incentive for sharing personal preferences with third parties. (World Economic Forum & Accenture, 2017)

However, getting permission to collect data is not *carte blanche* to treat customer data simply as a financially valuable asset. Being transparent about using data to address the issues discussed in the previous section, such as implicit bias, accessibility and wellbeing, could go a long way to re-building trust.

Possible solutions

The following suggestions have been drawn from the literature discussed in this section:

- Prioritise human experience and trust from design and implementation to iteration
- Source data from a more representative range of people to avoid biased algorithms
- Inform customers of how you will use their data at the point of capture and foster a culture of transparency
- Capture, analyse and value qualitative data that tell individual stories about how technology is or is not making people’s lives better

Challenge 5: Role of regulation

> *"The entire ecosystem of IoT consists of different players. The standardization of nanodevices from different manufacturers is essential to avoid interoperability issues. The IoT value chain includes connectivity providers, application service providers, and business management personnel. Everyone in this value chain follows their convenient standards and protocols, leading to incompatibility. This results in failure to reap the benefits of IoT."* (Technavio, 2017)

There is a real danger that regulatory frameworks will struggle to keep up with industry, resulting in security breaches or exploitation of sensitive data. Indeed, regulation is an important solution to most of the challenges discussed in this report; legal measures are a necessary part of ensuring safety and security, while sector-based standards and protocols could help to ensure interoperability and frictionless data sharing. According to Curado (2017), regulations "may slow the process of digital innovation in aerospace, but failure to consider them would jeopardize the safety considerations that are part of aviation's foundation."

Additionally, enterprises that rely heavily on data may face a difficult transition in the coming months with the implementation of data protection legislation such as the EU General Data Protection Regulation (GDPR). In this instance, businesses in aviation may find themselves needing to catch up with the law rather than the other way around.

Legal regulations and standards

Legal regulations and standards supporting data use need to come from an alignment between government and industry and be in the best interest of individuals (World Economic Forum & Accenture, 2017). Regulatory and statutory language needs to enshrine data use that enables "bidirectional exchange among, or access to, the full range of levels of models and databases" (Hale, 2017).

The next few months will see a change in data protection legislation that will be relevant to any enterprise operating in the EEA or UK. GDPR strengthens existing data protection laws, in part by introducing stricter penalties for violations. Businesses found in breach of the law can be fined up to €20 million, or 4% of its annual global turnover for every breach and directors of these businesses can be prosecuted. (Woolich, Kavanagh, & Burling, 2017) While the AEC sector does not hold much personal data currently, in looking forward to a Digital Built Britain it is essential to consider models of information management that will enable the secure, legal and transparent collection, storage and sharing of employee and customer data.

Vincent, Niezen, O'Kane, & Stawarz (2015) point to ways of addressing the challenge of ICT regulation, including open publishing of documentation, adding contextualised methods to usability standards, collaborative development of apps with end users, and development of standards and regulations with end users. While these solutions will not guarantee that regulations stay ahead of the technology curve, they would ensure that regulations reflect the needs of individuals and not simply the interests of enterprises.

Agreements and conventions

Safety and security may be the purview of legal regulations, but when it comes to interoperability it is often left to organisations to agree on standards and guidance. While volume of big data is being addressed with technical solutions such as cloud data storage, the variety of big data can only be addressed through "interoperability standards, conventions, and community engagement", according to Lynnes (2016). Aerospace uses ISO 10303-239 for interoperability, while aerospace-specific standards on IoT, big data and the digital twin are currently being drafted by SAE (Wasserman, 2018).

One example of community engagement is the Open Connectivity Forum (OCF), a group of technology firms interested in IoT who have united to develop standards that facilitate interoperability. "The OCF's vision for IoT is that billions of connected devices (appliances, phones, computers, industrial equipment) will communicate with one another regardless of manufacturer, operating system, chipset, or transport." This would make interoperability standards scalable from small technology firms to large multinationals. (Howard, 2016)

Possible solutions

- Establish frameworks for the appropriate use of data in consultation with industry and the public, including policies, standards and legislation
- Collaboration between government, industry and public representation will ensure that data regulation serves everyone's best interests
- Consider data protection not as an afterthought but as a core principle of the sector, and recruit people who will keep data protection and management standards and regulations at the forefront

Challenge 6: Investment

> *"'Leading aerospace and defense companies that invested early in IoT technologies are now realizing returns that range from overall product cost reduction due to manufacturing automation to delivering a better customer experience with preventive maintenance (resulting in higher product reliability and higher customer satisfaction).'"* (Howard, 2016)

Competition

Historically, the barriers to entry in both aerospace and aviation were prohibitively high. However, if "digital native" start-ups invest intelligently, they now have the potential to disrupt the market (World Economic Forum & Accenture, 2017). Aerospace giants like Boeing are already seeing competition from start-ups like SpaceX and Planetary Resources, and are feeling the pressure to automate and digitise as a result (Cox, 2017). IoT will increase the volume of data generated by sectors, and, "given the capital-intensive nature of the industry, the cost associations are expected to increase for the airline operators in the process of transformation toward IoT ecosystem." (Technavio, 2017) With the cost of digitalisation going up and the threat from newcomers, intelligent investment is crucial to seeing ROI from digital initiatives.

Knowing where to invest

One of the biggest barriers to digitalisation cited by business leaders is "finding the right digital solution, demonstrating the benefits of digital, and identifying the right technology provider or partner" (Ketzner & Cailliau, 2017), meaning that it is difficult for businesses to know how to invest. According to a survey by IFS (2017) there is a strong willingness across the sector to invest, but how are leaders in Aerospace and Aviation choosing which technologies to invest in? **FIGURE 3** shows key areas for investment and strategic focus in the near future. The areas within the blue circle are likely to be highly important in the future and are not currently areas of competitive excellence for the Aerospace and Defence sector. While technical investments are important, the human-focused areas highlighted will underpin the adoption and use of advanced technologies.

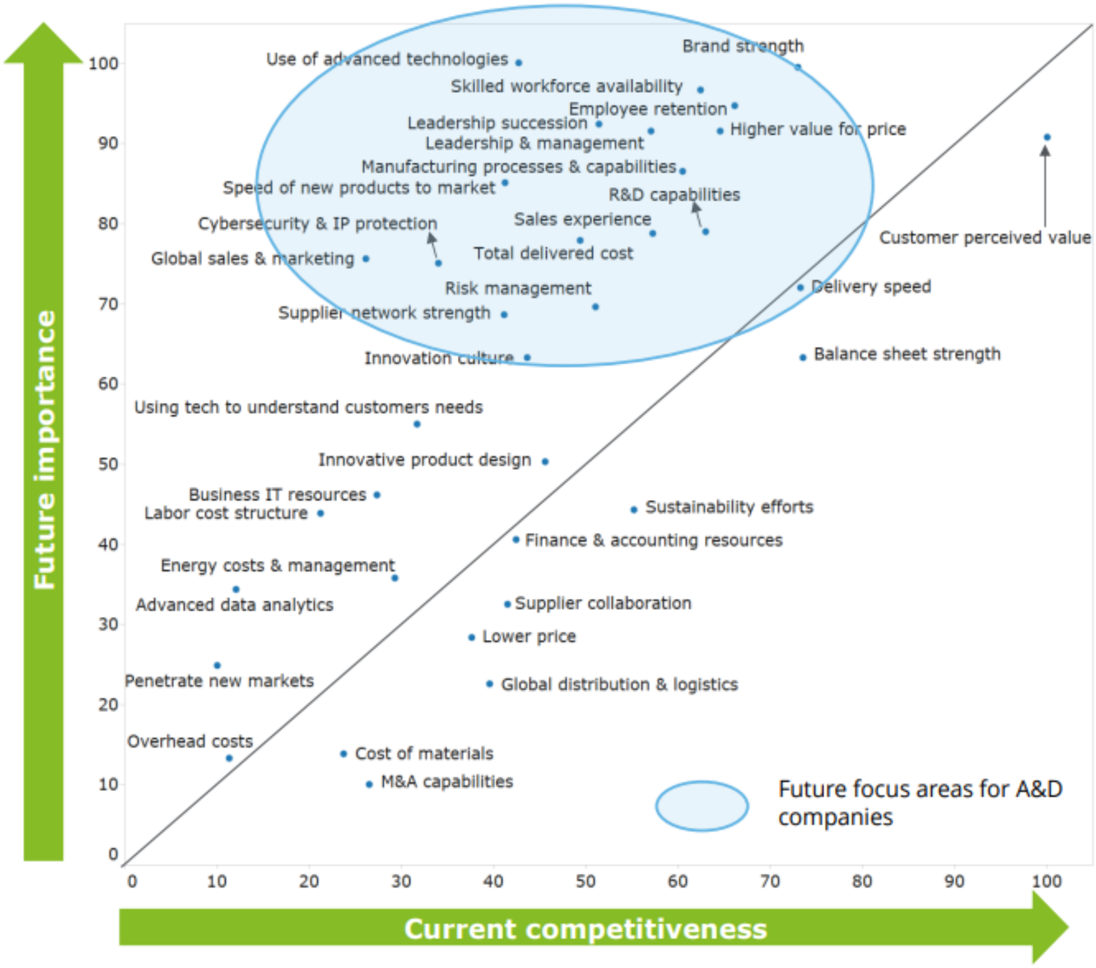

Figure 3 – Competitiveness map for Aerospace and Defence companies. Source: Deloitte (2018). Used with permission.

According to a study of the aerospace sector by the Boston Consulting Group (BCG), digital investment yielded positive results across the board, and early investment across functions achieve better than more selective spending. The wider variety of goals a business invested in digital in order to achieve, the better they performed, as shown in FIGURE 4. "Frontrunners also apply digital across a greater breadth of functions (for example, program management, engineering, supply chain, and production) and across activities within those functions." (Ketzner & Cailliau, 2017)

Level of investment made a difference in operations, but otherwise had less of an effect than what the investments were in (Ketzner & Cailliau, 2017). Light-touch, flexible investments are have had some success. The BCG study highlights a leading aerospace company that invested in more than 400 digital mini-projects, which cumulatively led to "a 300% increase in quality control productivity, improved life cycle inventory and extended product lifetimes for end users, and lower production and supply chain costs" over an 8 year period. These projects focused on solving specific problems and fed into a "digital menu" that from which all of the plants in the company could select, listing the available tools, results and contact information for experts who can help with deployment. This menu in turn has helped increase deployment. (Ketzner & Cailliau, 2017) This menu idea is reiterated by Baig, Baptista, Coleman, & Roller (2017), who recommend that "companies should start with a long menu of potential initiatives, ranging from those aimed at powering growth with better products, services, and customer experiences, to those seeking greater efficiency in operations such as engineering, supply-chain management, and back-office support."

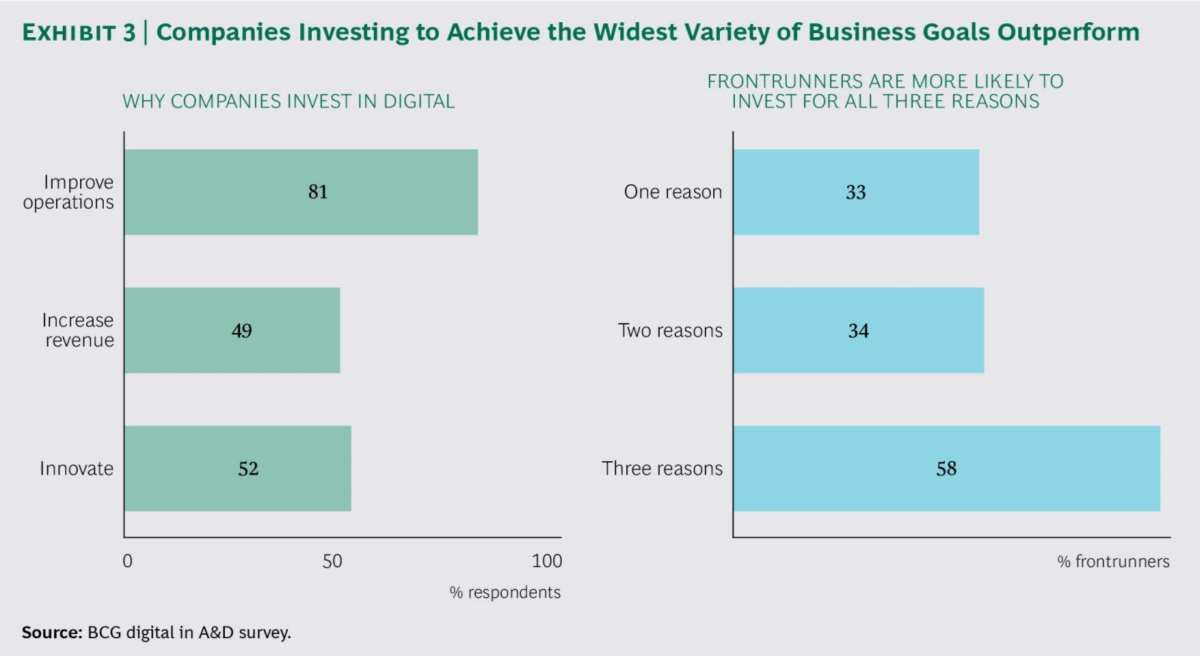

Figure 4 - Aerospace leaders invest in digitisation for the widest variety of business goals. Source: Becoming a Digital Frontrunner in Aerospace and Defense, The Boston Consulting Group, 2017. Used with permission.

Apps may represent another useful model of investment, with lower cost and more flexibility. Many airports are already capturing customer data through apps and, as discussed in Report 2.1, this may be a useful way of staying up-to-date without having to uproot a complex data infrastructure with each new advance in technology (Technavio, 2017). At Airbus, creating user-friendly, app-like interfaces for automated technology is a way of retaining their workforce. "Today we all use smartphones – why shouldn't we be able to control a robot through an app as well? We have to react quicker, continually taking on board new developments and adapting accordingly." This investment based on a particular strategic aim – leveraging data to make manufacturing more efficient – is another way to choose where to invest. In this case it also had the benefit of supporting rather than replacing workers. (Raveling, 2017)

Possible solutions

The following suggestions have been drawn from the literature discussed in this section:

- Centre digital projects around empowered digital leaders and flexible teams that will focus on producing minimum viable products
- Engage in systems thinking
- Set targets for cost savings, operational efficiency, revenue growth and innovation, and monitor results
- Invest ahead of the business case

- Be strategic about when to develop digital technology and when to go with ready-made, taking advantage of strategic partnerships
- Focus on a smaller number of high-value digital initiatives

Overview of the literature

Compared to the previous report, the academic literature on the aerospace and aviation sectors is more dispersed and the University has better access to it, whereas the grey literature identified in this search is less concise than the market reports for upstream O&G. This is compounded by the fact that, unlike AEC, aerospace and aviation do not have a "BIM" equivalent: an all-encompassing term for the collection, storage, modelling and analysis of data throughout asset lifecycles. FIGURE 6 outlines some of the searching difficulty resulting from this situation. Using "information management" retrieves relevant results, but may miss where more specialist language is used to describe techniques and outcomes related to information management. Searching t he literature and consolidating these sectors into key challenges was therefore more difficult than with O&G.

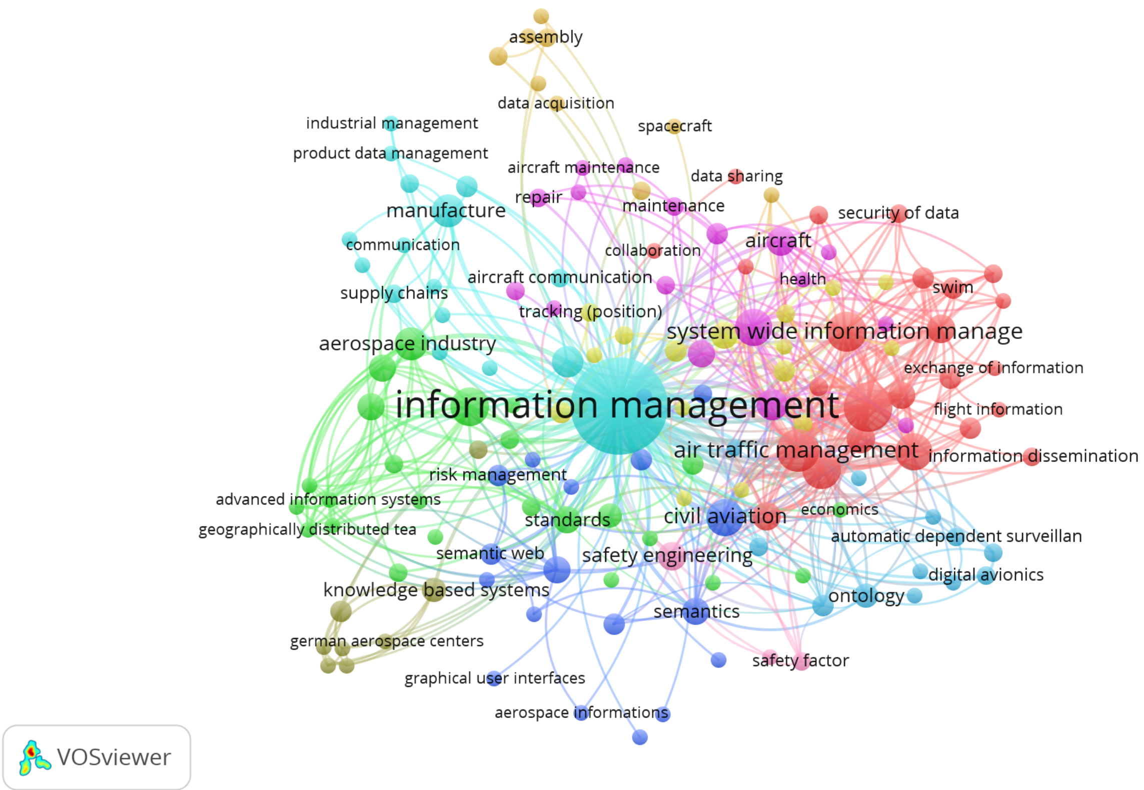

Figure 1 - A keyword co-occurrence map where all searches involved the phrase "information management".

The academic literature is most often focused on specific technical solutions and where authors have considered a wider perspective on challenges and solutions is found in news articles, blogs and industry reports. SAE Mobilus holds technical papers and standards for the sector, while IEEE has more resources on data management. Conference papers and technical papers lead the document types on this topic, possibly due to the speed of technological development.

Centre for Digital Built Britain

Bibliometric review

Research outputs tend to come from specialist technical universities (e.g. Georgia Institute of Technology, Civil Aviation University of China, Embry Riddle Aeronautical University) or aerospace/aviation firms themselves (e.g. Boeing, Raytheon, NASA). Scopus did not identify any institutions as being highly prolific on these topics and the more relevant work is likely to be published by organisations that have a data and information technology focus, such as IEEE.

China and the United States tend to lead in terms of numbers of publications, but none of the searches revealed authors leading the pack of those who had published two or three relevant documents. Because of the lack of key authors and the technical specificity of the sectors, the potential for finding academic collaborators for CDBB in this field is low. However, it may be worth engaging with the existing digital champions in the industry. According to Nigam (2016) airlines are beginning to hire talent from digital companies. For example, Air New Zealand hired chief digital officer Avi Golan, who had previously held senior leadership positions at Google and Intuit. These digital leaders integrating with engineering sectors may be key contacts for CDBB moving forward.

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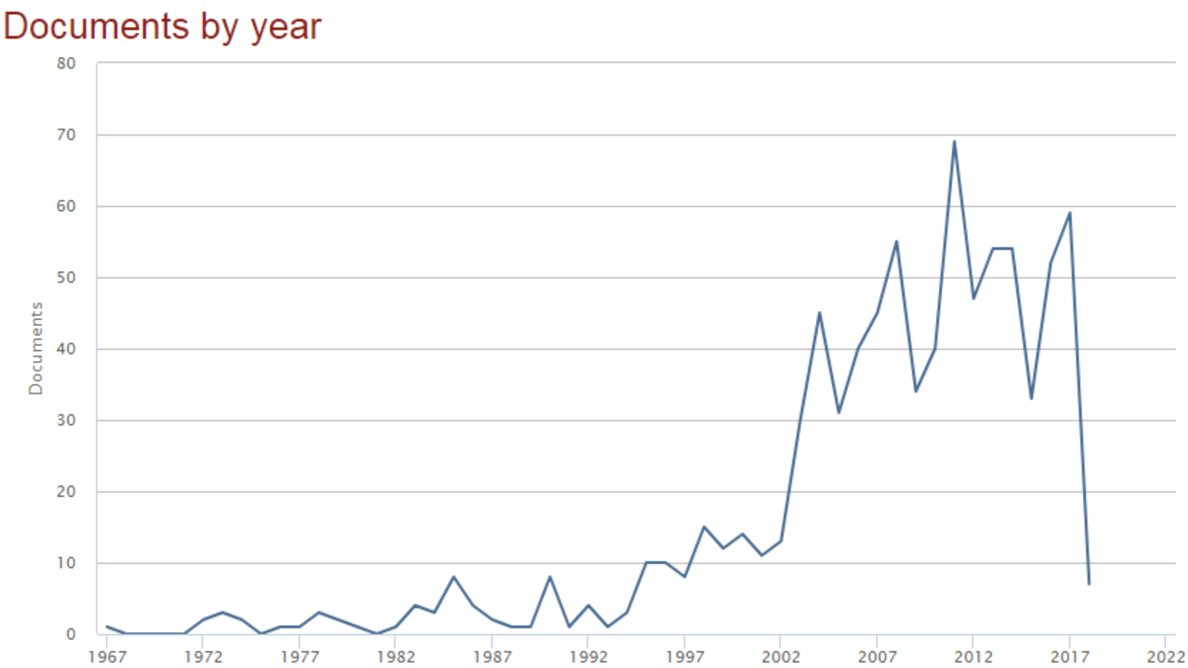
Appendix: Bibliometric evidence

Publishing patterns

The table below shows the publication patterns for this search, with sudden growth in the early 2000s when the average publication rate per year climbs from the teens to the forties, peaking in 2011 with 69 documents. This indicates that it has become a more consistent topic within the academic literature. With each of the searches conducted in this area there is not the steady climb in publications seen in the BIM literature (Report 1.3).

Scopus 20/03/18:

(TITLE-ABS-KEY ("data architecture" OR "information architecture") OR TITLE-ABS-KEY ("data management" OR "information management") AND TITLE-ABS-KEY (aerospace OR aviation)) AND (EXCLUDE (SUBJAREA , "EART") OR EXCLUDE (SUBJAREA , "PHYS") OR EXCLUDE (SUBJAREA , "ENVI") OR EXCLUDE (SUBJAREA , "ENER") OR EXCLUDE (SUBJAREA , "CENG") OR EXCLUDE (SUBJAREA , "HEAL") OR EXCLUDE (SUBJAREA , "BIOC") OR EXCLUDE (SUBJAREA , "NURS") OR EXCLUDE (SUBJAREA , "PSYC") OR EXCLUDE (SUBJAREA , "AGRI") OR EXCLUDE (SUBJAREA , "ARTS") OR EXCLUDE (SUBJAREA , "CHEM") OR EXCLUDE (SUBJAREA , "NEUR") OR EXCLUDE (SUBJAREA , "PHAR") OR EXCLUDE (SUBJAREA , "Undefined")) = 845



Top sources

IEEE 20/03/18:

(((aviation) OR aerospace) AND "data management") = 197

1. Aerospace and Electronic Systems Magazine, IEEE (7)
2. Proceedings of the IEEE 1993 National Aerospace and Electronics Conference, 1993. NAECON 1993.(4)
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6. IEEE/AIAA/NASA 9th Digital Avionics Systems Conference, 1990. Proceedings. (3)
7. Aerospace Conference, 2011 IEEE (3)
8. Integrated Communications, Navigation and Surveillance Conference, 2009. ICNS '09. (3)

Scopus 20/03/18:

(TITLE-ABS-KEY ("data architecture" OR "information architecture") OR TITLE-ABS-KEY ("data management" OR "information management") AND TITLE-ABS-KEY (aerospace OR aviation)) AND (EXCLUDE (SUBJAREA , "EART") OR EXCLUDE (SUBJAREA , "PHYS") OR EXCLUDE (SUBJAREA , "ENVI") OR EXCLUDE (SUBJAREA , "ENER") OR EXCLUDE (SUBJAREA , "CENG") OR EXCLUDE (SUBJAREA , "HEAL") OR EXCLUDE (SUBJAREA , "BIOC") OR EXCLUDE (SUBJAREA , "NURS") OR EXCLUDE (SUBJAREA , "PSYC") OR EXCLUDE (SUBJAREA , "AGRI") OR EXCLUDE (SUBJAREA , "ARTS") OR EXCLUDE (SUBJAREA , "CHEM") OR EXCLUDE (SUBJAREA , "NEUR") OR EXCLUDE (SUBJAREA , "PHAR") OR EXCLUDE (SUBJAREA , "Undefined")) AND (LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013)) AND (EXCLUDE (SUBJAREA , "MATH") OR EXCLUDE (SUBJAREA , "MEDI") OR EXCLUDE (SUBJAREA , "SOCI") OR EXCLUDE (SUBJAREA , "MATE") OR EXCLUDE (SUBJAREA , "ECON")) = 197

1. Applied Mechanics And Materials (12)
2. AIAA IEEE Digital Avionics Systems Conference Proceedings (9)
3. Advanced Materials Research (6)
4. Annual Forum Proceedings AHS International (5)
5. Procedia CIRP (5)
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7. Procedia Computer Science (4)

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“information management”

1. Ford Motor Company (6)
2. Ford Motor Co. (5)
3. Federal Highway Administration (4)
4. Georgia Institute of Technology (4)
5. Information Management Consultants, Inc. (4)
6. NASA Ames Research Center (4)
7. KRUG Life Sciences (3)
8. National Highway Traffic Safety Administration (3)

Scopus 20/03/18:

(TITLE-ABS-KEY ("data architecture" OR "information architecture") OR TITLE-ABS-KEY ("data management" OR "information management") AND TITLE-ABS-KEY (aerospace OR aviation)) AND (EXCLUDE (SUBJAREA , "EART") OR EXCLUDE (SUBJAREA , "PHYS") OR EXCLUDE (SUBJAREA , "ENVI") OR EXCLUDE (SUBJAREA , "ENER") OR EXCLUDE (SUBJAREA , "CENG") OR EXCLUDE (SUBJAREA , "HEAL") OR EXCLUDE (SUBJAREA , "BIOC") OR EXCLUDE (SUBJAREA , "NURS") OR EXCLUDE (SUBJAREA , "PSYC") OR EXCLUDE (SUBJAREA , "AGRI") OR EXCLUDE (SUBJAREA , "ARTS") OR EXCLUDE (SUBJAREA , "CHEM") OR EXCLUDE (SUBJAREA , "NEUR") OR EXCLUDE (SUBJAREA , "PHAR") OR EXCLUDE (SUBJAREA , "Undefined")) AND (LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013)) AND (EXCLUDE (SUBJAREA , "MATH") OR EXCLUDE (SUBJAREA , "MEDI") OR EXCLUDE (SUBJAREA , "SOCI") OR EXCLUDE (SUBJAREA , "MATE") OR EXCLUDE (SUBJAREA , "ECON")) = 197

1. Civil Aviation University of China (9)
2. Cranfield University (5)
3. Deutsches Zentrum fur Luft- Und Raumfahrt (5)
4. Beihang University (5)
5. Chinese Academy of Sciences (5)
6. Embry Riddle Aeronautical University (5)
7. Universidad Carlos III de Madrid (4)
8. Electronic Navigation Research Institute (4)
9. Shenyang Aerospace University (4)
10. Harris Corporation (4)

(TITLE-ABS-KEY ("Cyber-physical system") AND TITLE-ABS-KEY (aerospace OR aviation)) AND (LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013)) AND (LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "COMP") OR LIMIT-TO (SUBJAREA , "DECI")) = 87

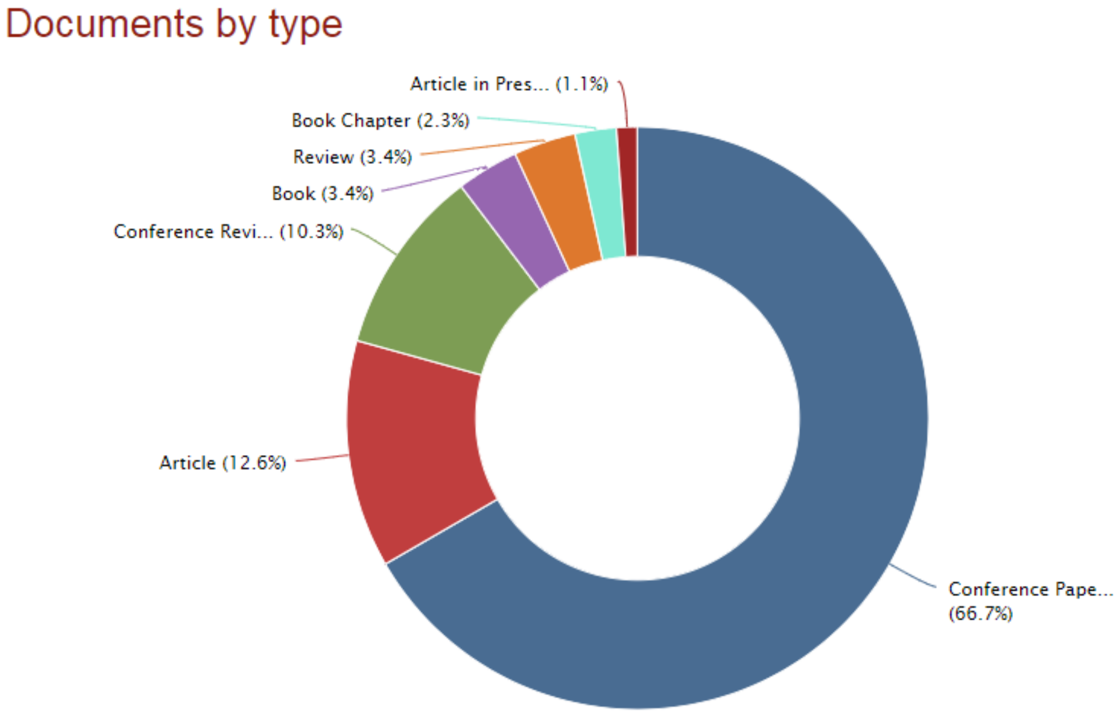
1. Guangdong University of Technology (11)
2. East China Normal University (11)
3. Simula Research Laboratory (3)
4. Raytheon (3)
5. Georgia Institute of Technology (3)
6. Carnegie Mellon University (3)
7. Boeing Corporation (3)
8. California Institute of Technology (3)

Scopus 21/03/18:

(TITLE-ABS-KEY (data W/2 model*ing) OR TITLE-ABS-KEY (information W/2 model*ing) AND TITLE-ABS-KEY (aerospace OR aviation)) AND (EXCLUDE (SUBJAREA , "MEDI") OR EXCLUDE (SUBJAREA , "ENVI") OR EXCLUDE (SUBJAREA , "HEAL") OR EXCLUDE (SUBJAREA , "AGRI") OR EXCLUDE (SUBJAREA , "ARTS") OR EXCLUDE (SUBJAREA , "NEUR") OR EXCLUDE (SUBJAREA , "PSYC") OR EXCLUDE (SUBJAREA , "BIOC") OR EXCLUDE (SUBJAREA , "CHEM")) = 249

1. NASA Ames Research Center (7)
2. NASA Langley Research Center (6)
3. NASA Goddard Space Flight Center (6)
4. Georgia Institute of Technology (6)
5. Boeing Corporation (6)
6. Deutsches Zentrum fur Luft- Und Raumfahrt (5)
7. MITRE Corporation (5)
8. University Michigan Ann Arbor (5)
9. University of Sheffield (4)
10. Beijing Institute of Technology (4)
11. University of Minnesota Twin Cities (4)

Document types



Scopus 20/03/18:

(TITLE-ABS-KEY ("Cyber-physical system") AND TITLE-ABS-KEY (aerospace OR aviation)) AND (LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013)) AND (LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "COMP") OR LIMIT-TO (SUBJAREA , "DECI")) = 87

SAE Mobilus 20/03/2018:

"information management" = 403

1. Technical Paper (309)
2. Aerospace Standard (31)
3. Journal Article (21)
4. Magazine Article (16)
5. Ground Vehicle Standard (4)
6. Magazine Feature Article (2)
7. Special Publication (SP) (1)
8. Standard (1)