Predictive maintenance
offers a crucial step forward

Diagnosing problems in advance will help the airline industry to keep aircraft flying and prevent costly groundings. **Bernie Baldwin** learns about predictive maintenance from leading practitioners

Just as nature abhors a vacuum, the airline industry feels similarly about an aircraft-on-ground (AOG) situation, where revenue-generating vehicles are prevented from doing their job. Knowing ahead of time that a module, part or component is likely to fail shortly means airlines can prepare and ensure that a necessary replacement can be accomplished in a just-in-time manner, thus keeping the aircraft airworthy as much as possible.

This process of advanced diagnostics, known as predictive maintenance (PdM), is becoming more prevalent across the industry, with many airlines and OEMs adopting such solutions. Seth Babcock, head of Tech Ops Solutions and Data Analytics at Collins Aerospace, offers his thoughts on the key elements of a predictive maintenance programme and the drivers that make the business case for its adoption.

"Predictive maintenance is an important application of data analytics in aviation. This involves using data to predict when aircraft maintenance is likely to be needed, allowing for proactive repairs and replacements before a problem occurs," Babcock confirms. "By implementing predictive maintenance programmes, airlines can reduce the risk of equipment failures and ensure that their aircraft operate at peak performance.

"Beyond helping to prevent maintenance events, predictive maintenance has other potential benefits. In the area of repair costs, by proactively addressing part failures before they occur, ancillary damage to other parts of the

Honeywell's analytics will now help AVIATAR's predictive health analytics to predict the behaviour of systems and components during operation
Honeywell

aircraft may be prevented, turning a major repair into a minor repair," he continues. "Then, when scheduling maintenance, by timetabling the event, the operator can ensure that the right people, material, and tooling are in place to complete the task. This reduces strain on the overall network and supply chain."

Targeted troubleshooting is also helped. "Often, troubleshooting involves trying to recreate the fault during ground operations. This is sometimes impossible because of different operating conditions. Because the recommendation is based on data, the action the operator takes is often targeted to the specific component and failure mode," Babcock adds. "Finally, by preventing the maintenance event, an airline can help pilots and ground crews focus on specifically identified areas of repair and maintenance instead of drawing attention away to chase unknown failure situations, which can help improve the overall safety of the operation.

"The benefits of data analytics and predictive maintenance in aviation are numerous. By improving the reliability of aircraft and equipment, airlines can reduce the likelihood of delays and cancellations while also increasing safety for passengers and crew," he declares.

AJW Group's technical director, David Miret Mora, believes that predictive maintenance holds excellent potential for aviation. However, he thinks its adoption faces complexity due to regulatory gaps and the absence of a structured framework. "Presently, aviation regulations lack a defined PdM structure, creating a significant barrier to its acceptance across different aviation key players," he explains. "To unlock its benefits, a PdM framework is imperative to align stakeholders' interests and establish a consistent maintenance strategy.

"Historically, aviation maintenance followed structured schedules, with pioneers like Nowlan and Heap introducing reliability-centred maintenance (RCM) in 1978, leading to the MSG-3 logic methodology [created by the Air Transportation Association (ATA), the forerunner of Airlines for America (A4A)]. Recent innovations, like aircraft health monitoring (AHM) systems, have transformed maintenance practices," Miret Mora adds. "However, a definitive PdM technology framework remains undefined, necessitating a comprehensive approach to address limitations, consequences, and industry-wide challenges.

"Traditional maintenance emphasises scheduled maintenance to achieve cost-effective airworthiness. PdM offers an analytical approach, potentially optimising maintenance by preventing premature or delayed component replacements," he remarks. "Nevertheless, formal research is needed to validate its superiority.

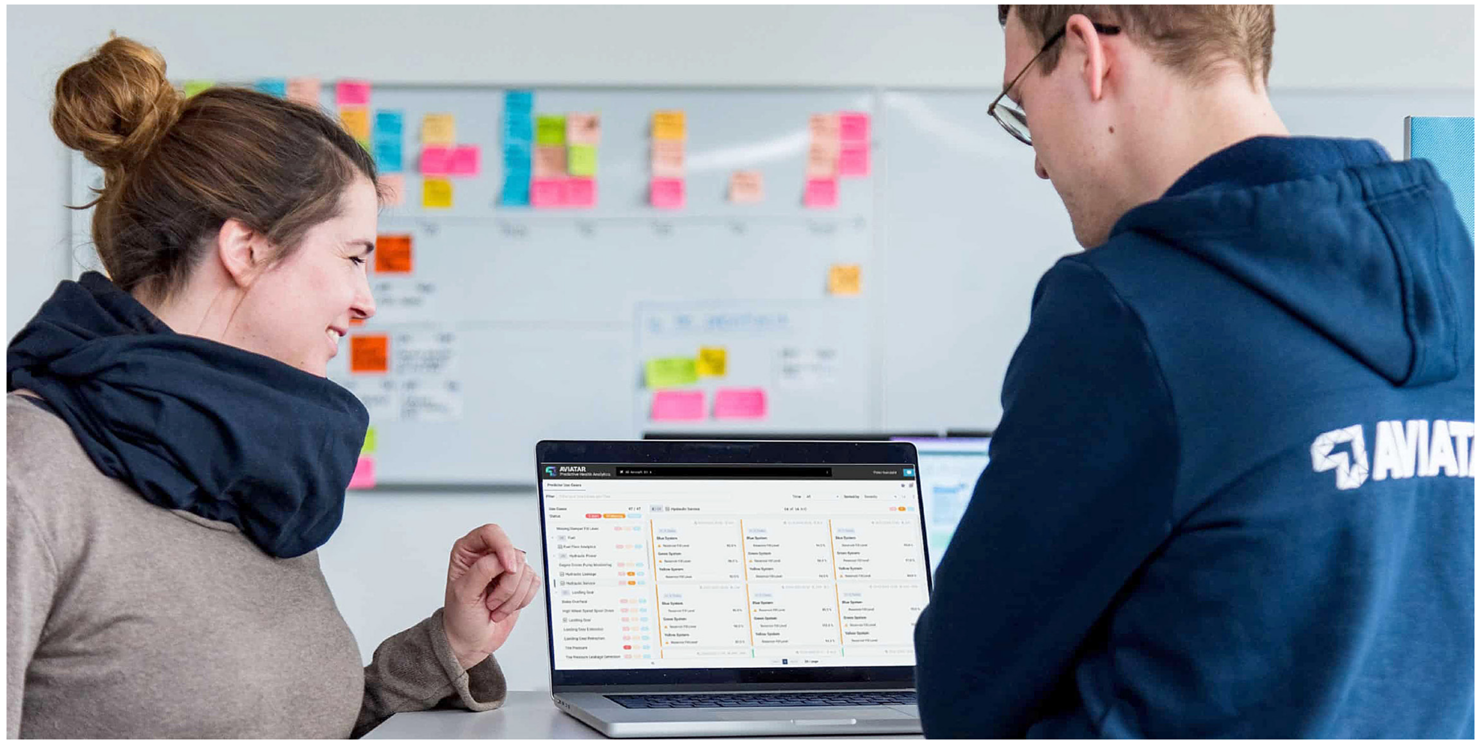
"Digital solutions, including PdM, are gaining traction in aircraft maintenance, driven by their potential to enhance operators' availability and reduce airline operational costs. Airlines are eager to invest, but the challenge lies in gaining acceptance from regulators, MRO providers, suppliers, OEMs, and other stakeholders.

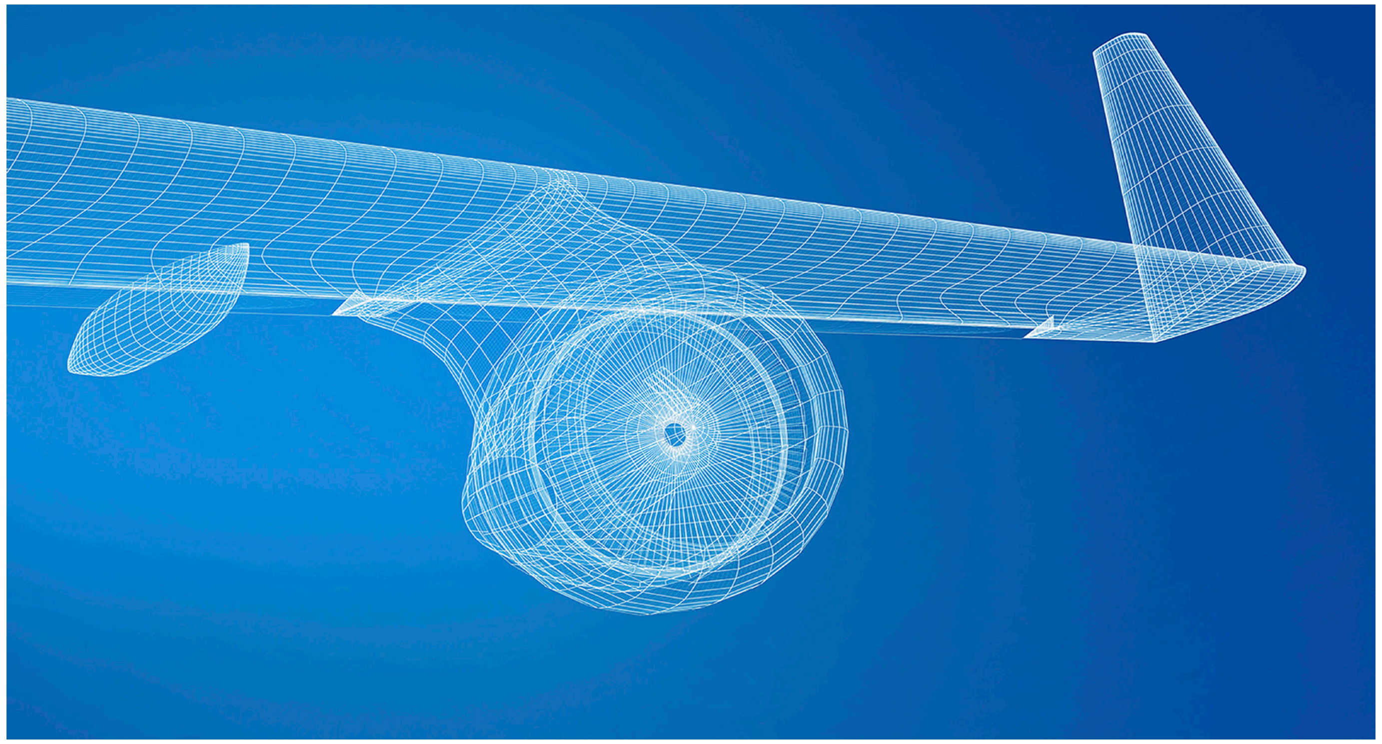
"Airlines stand to benefit most from PdM, but its successful implementation requires industry-wide readiness," Miret Mora argues. "Unanticipated consequences may emerge at both on-wing (such as unnecessary line maintenance activity) and off-wing maintenance levels (such as a potential increase in removals or higher NFF (no fault found) rates due to an early removal and not being able to detect the failure mode). The lack of unity among stakeholders further complicates matters. PdM's emergence in aviation maintenance is still in its early stages, raising fundamental questions that demand collaborative solutions."

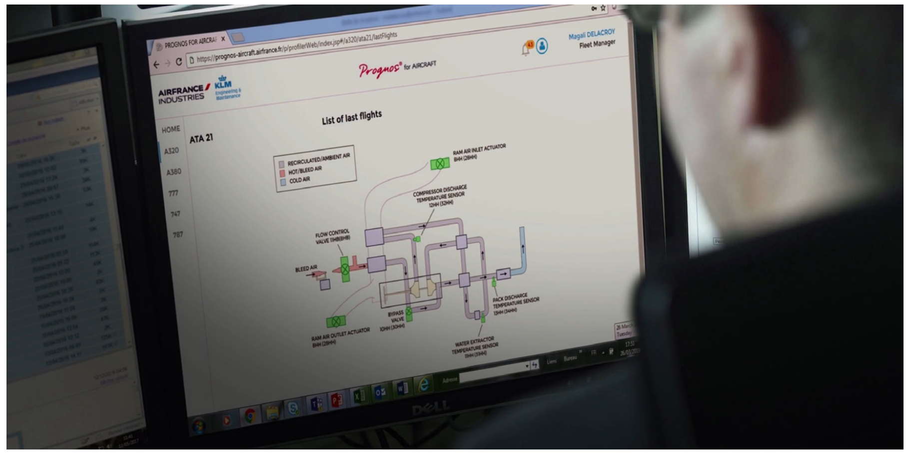
For Steve Schoonveld, director of product management, Connected Aircraft at GE Aerospace, a predictive maintenance programme is a three-legged stool of processes, people and data. "Predictive maintenance is a cultural shift, which requires changing parts or performing maintenance before something breaks. This is a process change for most operators, and having a champion that understands and supports that shift is key. Truly effective programmes embed predictive maintenance as part of the day-to-day operations," he observes.

"More tactically, successful teams must have domain expertise, specifically an understanding of aircraft design, operations, and data science. It's essential to understand how a system is designed to work, how it is actually used in operation, and then how to pull the data needed.

Lastly, quality data sets are only valuable when put in the hands of a skilled team," Schoonveld emphasises. "Recording the right data and then getting a consistent and timely flow enables all the downstream predictive analytic processes. We often encourage customers to start with their data, whether sourced from a flight recorder or a dedicated health monitoring system. This allows for a quick start and highlights what gaps in data flow need to be addressed."







CLOCKWISE FROM OPPOSITE:

Honeywell formed a partnership with Lufthansa Technik in 2023, licensing the analytics to the latter for deployment in its AVIATAR platform
Honeywell

Engine health monitoring is a vital part of predictive maintenance
Lufthansa Technik

Seen by AJW Group technical director, David Miret Mora, as an early adopter of predictive maintenance, Air France Industries KLM Engineering & Maintenance has developed its own solution, Prognos
KLM Engineering

Matthew Emery is the digital maintenance solutions product manager at Honeywell Connected Aerospace. He reports that while the company's connective maintenance offering has ended and the analytics licensed to Lufthansa Technik for deployment in the AVIATAR platform, Honeywell still has many other digital maintenance offerings, such as PTMD (Predictive Trend Monitoring and Diagnostics), Engine Health Monitoring and Maintenance Advisor.

Data driven

For Emery, the key elements of a predictive maintenance programme are led by "good timely data, accurate and proven analytics and clear insights/recommendations".

There are, of course, many parameters monitored on an aircraft. Getting the most important intelligence for operations may mean prioritising some, probably depending on how mission-critical a system is.

"Yes," says Emery, "When developing our algorithms, we target the systems and components that have the largest impact – namely those which can cause AOG, delays, cancellations, performance penalties and are difficult to troubleshoot on airline operations such as auxiliary power units (APUs), air-conditioning,

> *"Predictive maintenance is a cultural shift, which requires changing parts or performing maintenance before something breaks"*
> Steve Schoonveld, director of product management, Connected Aircraft at GE Aerospace

pneumatics and landing gear."

AJW's Miret Mora notes how the aviation world has seen a surge in data with the rise of e-enabled aircraft. "For instance, a Boeing 787 with Rolls-Royce engines can generate 500GB of data per flight, and an Airbus A350's 50,000 onboard sensors amass 2.5 terabytes of data daily. This data influx presents a major challenge – distinguishing critical information from noise," he states.

"Aviation experts, whether in airline operations or product development, grapple with the need to prioritise data parameters, a crucial aspect of effective PdM in aviation. Leading players like Airbus and Boeing recognise that successful PdM adoption requires collaboration across four key segments: engineering analytics, data management, decision-making processes, and software development," Miret Mora elaborates. "They have refined their data analytics capabilities and partnered with non-aviation companies to seamlessly integrate PdM software such as IBM, Microsoft, and so on.

"The spectrum of data, however, varies by aircraft generation. Older designs like the A320ceo have limited sensor coverage, mainly for flight controls, hindering comprehensive health monitoring. This emphasises the importance of data availability from these sensors for effective PdM," the AJW exec adds.

"Furthermore, PdM algorithms often focus on detecting specific component failure modes rather than addressing all potential failures of a component. For instance, an algorithm might target electrical malfunctions in a component such as the pressure regulator valve (PRV), leaving other failure modes unattended. The effectiveness of PdM depends on the sensors' ability to measure relevant parameters.

"To illustrate, an analysis of the PRV electrical failure algorithm found it identified only 20.9% of annual removals, with traditional maintenance practices accounting for the remaining 79.1%. Transitioning fully to PdM for complex components like avionics necessitates developing multiple algorithms, constrained by sensor coverage and complexity," Miret Mora remarks.

Collins' Babcock acknowledges that many parameters monitored on aircraft trigger events such as fault codes or ACMS messages but says only a small number of those parameters are recorded and transmitted to the ground.

"When it comes to predictive maintenance, airlines are learning that the standard data supplied in the Arinc 717 FOQA data feed is limited, and more data is needed to develop analytics for complex systems like pneumatics, air management, hydraulics, and electrical power. Many are considering aircraft interface devices that enable the airline to connect to many additional Arinc 429 connections and record these parameters on that device," he adds.

"Today's modern aircraft have millions of parameters flowing through their networks. As predictive maintenance becomes more of a common industry-adopted tool, this will push the industry to record more data, as close to native rates as possible, to enable deeper analytics to be developed," Babcock predicts.

According to GE's Schoonveld, modern systems can capture all, or nearly all, the traffic on aircraft networks. "It's critical to be able to prioritise the data that is most valuable, and often that comes down to the components and systems that are causing the most disruption," he explains. "We collaborate with our customers to identify the top issues and then systematically address those by focusing on obtaining and curating the needed data. Leading health monitoring systems also allow for rapid updates to change what data is collected so they can grow with an operation over time.

"The depth of the diagnostics is a function of the data collected. Frequently, individual components can be diagnosed. In cases where the data doesn't support isolation to a line replaceable unit (LRU), we often find that the set of possible causes or areas to investigate can be reduced, allowing the aircraft mechanic to target their efforts and quickly return the aircraft to service," Schoonveld elaborates.

Perfect timing

Successful predictive maintenance demands that parts are in place at precisely the right time. Different ideas exist on how this is best achieved and what hurdles must be overcome.

"Ordering and moving parts based on predictive maintenance is a cultural shift," Schoonveld observes. "Ultimately, people need to be able to trust that they are doing the right thing and be incentivised to order parts before a failure. Predictive maintenance is a collaborative effort, and successful programmes engage cross-functional teams at the start to ignite that cultural shift.

"Secondly, integrating aircraft data with MRO systems is another big leap forward in productivity. Remaining useful life forecasts and predicted failures complement traditional demand planning techniques to ensure the right parts are where you need them," he states.

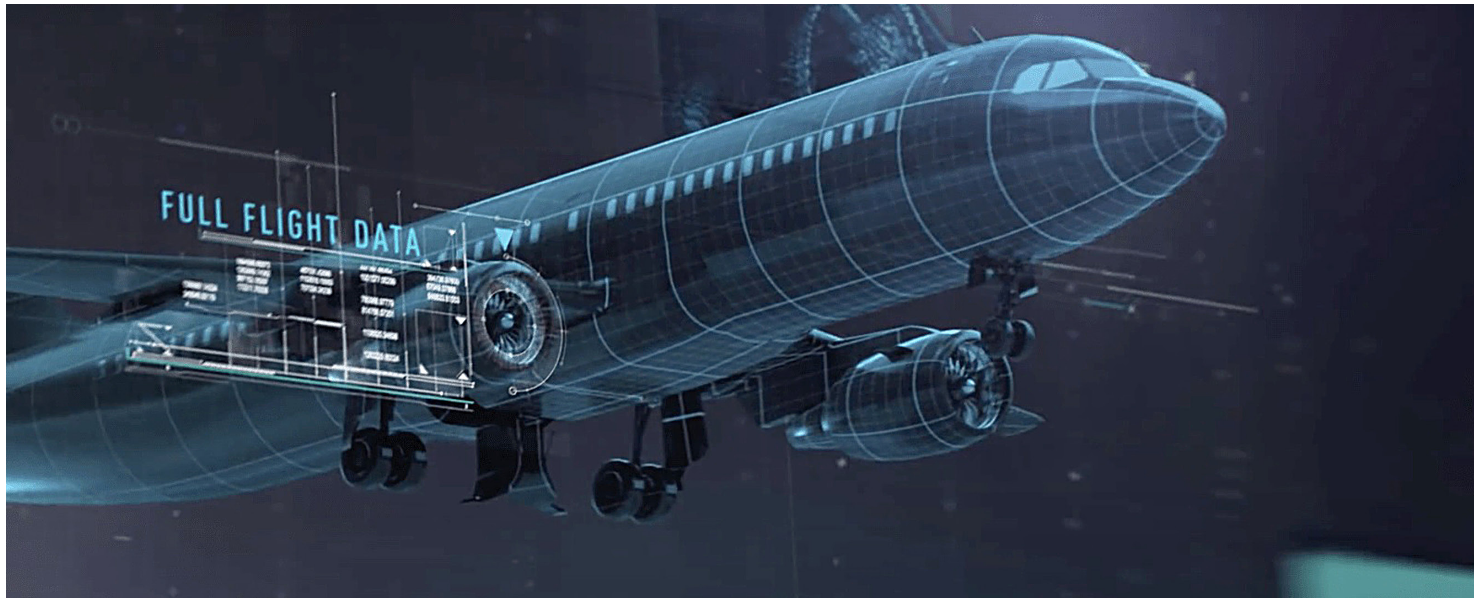
While AJW's Miret Mora agrees that predictive maintenance offers the advantage of precise parts planning, he believes it poses challenges that must be addressed. "While PdM enhances planning by anticipating potential component removals, it may sometimes increase removal rates. This can necessitate higher inventory levels to meet the demand for replacements," he elucidates. "On one hand, PdM pre-emptively schedules removals to prevent AOG situations. On the other hand, it may require more significant investments in inventory due to increased removals.

"This balance presents a significant industry challenge. While PdM helps airlines avert AOG events, it can lead to more removals in certain algorithms. Illustrated in the graph for a component in ATA 32, the combination of traditional removals (US) and PdM removals (PdM) results in a higher number of removals, thus raising repair costs. The price has increased by over 250%, with a 118% increase in removals. This is an extreme case to give a perspective of some algorithms," Miret Mora notes. "Achieving a harmonious balance between these conflicting aspects requires industry-wide collaboration and solutions to optimise overall maintenance strategies."

Collins' Babcock looks at the parts availability challenge from first principles. "Parts rarely fail overnight. There is typically a signal or trend of declining performance weeks to months before the failure," he confirms. "Our data science team is focused on identifying these scenarios and providing an average lead time to failure of 30 days. This ensures the airline has enough time to react and plan repairs while avoiding removing the component before a significant portion of its RUL (remaining useful life) has been consumed.

"As soon as an alert is triggered in Ascentia [Collins' analytics solution], the airline can begin planning for repairs. This means moving the right parts and materials to meet the aircraft and scheduling the repair task. The operator can identify when they are underutilising their manpower and schedule the repair," he adds, noting that without a PdM programme, the part might fail and could result in excess costs for AOG material allocation.

"Sometimes, a maintenance station runs out of components or tools because of a prior, inaccurate fault diagnosis. A deferred item provides an opportunity to re-evaluate the solution required for the fix. With a PHM (prognostics and health management) solution, troubleshooting effectiveness significantly improves, as it precisely identifies the necessary components for the repair," Babcock remarks.



OPPOSITE TOP:
Embraer is another "early adopter" of predictive maintenance, with its AHEAD (Aircraft Health Analysis and Diagnosis) system, to which Scoot was recently signed
Embraer

OPPOSITE BOTTOM:
Collins Aerospace's sister company within RTX, Pratt & Whitney, offers engine health management services
Collins Aerospace

Honeywell's Emery concurs that PdM should give notification before component failure, allowing the operator time to plan and order spares. "Whereas diagnostic maintenance analytics improve troubleshooting of a failed component, in this case, you would need to have a spare at the point of failure. For improving spares availability, you would need insights on your spares pool and usage," he comments.

Adopting PdM can come down to how much of an investment is required and the return time on that investment. "It depends on how you intend to use the system, the digital/data skills of your engineers and their trust in the data," Emery posits. "If it becomes a tool for your MOC/MCC (Management Of Change/Maintenance Control Centre), the upfront investment in training will be higher, but the investment should be lower over time. However, if you set up a team that is purely focused on the digital side, then the investment is likely to be higher over a period of time but smaller on the upfront training."

Steve Schoonveld states that with the infrastructure in place to obtain aircraft data, the ROI on predictive maintenance projects can be as little as 12 months. "The rotorcraft industry has used analytics for decades. On rotorcraft applications, health monitoring systems can deliver a 9% increase in aircraft availability and savings of over $100k/year per aircraft. Customers tell us that for every $1 put into health monitoring, they get $2 back.

"Military and civil fixed-wing operators are looking to gain similar results and are accelerating their use of aircraft data to improve aircraft availability and reliability. Even on legacy platforms, starting a PdM programme using flight recorder data can provide significant improvements," Schoonveld states.

Seth Babcock says that people often think there is a significant barrier to entry to PdM because of the procurement and installation of an Aircraft Interface Device (AID). "With a 30-day predictive lead time, though, the operator can proactively download their data weekly and still have time to prevent a maintenance event. Operators can start with this approach to keep costs low and build the justification to automate the process through an AID as they see successes with their programme.

"Another common barrier is the requirement for a dedicated team to monitor the alerts generated by a PHM system and translate them into maintenance actions. However, as part of our Ascentia solution, Collins Aerospace now has a dedicated team to monitor alerts," Babcock reports.

"Presently, aviation regulations lack a defined PdM structure, creating a significant barrier to its acceptance"
David Miret Mora,
Technical director, AJW Group

Future outlook

Beyond ROI for companies, AJW Group's David Miret Mora is concerned with how much the industry adopts PdM. "It varies significantly among different stakeholders, reflecting diverse levels of technological readiness and strategic approaches. In this context, one can divide industry stakeholders' level of commitment to PdM into five categories," he comments.

"Innovators are the tech enthusiasts, represented by OAMs (Offerings in the After Market), leading PdM technology development. For instance, Airbus's Skywise product is an industry leader, reflecting substantial investments in advancing maintenance practices.

"Moving to early adopters, these are our visionaries – major airlines benefitting from PdM, recognising its potential ROI, notably in reducing EU261 compensation costs," Miret Mora emphasises. "Some develop their PdM solutions, positioning as competitors to established leaders, such as Prognos (by Air France Industries KLM Engineering & Maintenance) and Aviatar (by Lufthansa Technik).

"Small airlines form the pragmatists, appreciating PdM's benefits but carefully assessing ROI against their operational dynamics. They might prioritise cost-saving measures like Soft-Time or reduced Visual Check Intervals," he continues. "Suppliers and AMOs (Authorised Maintenance Organisations) under Part 145 fall into the Late Majority and are the conservatives who have yet to develop robust PdM software or a clear adoption strategy, trailing behind OAMs and OEMs.

"Finally, regulators are the laggards, the industry sceptics, facing challenges integrating PdM into aviation, given their reliance on the MSG logic framework. They must decide whether to invest in aligning with PdM practices or maintain the current regulatory status quo.

"Achieving widespread adoption of PdM across all industry players requires addressing these challenges and fostering collaboration among stakeholders," Miret Mora declares.

The AJW Group technical director believes that PdM is poised to reshape aviation maintenance. "As technology rapidly advances, with innovations like composite materials, IoT (Internet of Things), AI (Artificial Intelligence), and ML (Machine Learning), the aviation industry must formalise its approach for the next maintenance era. Successful adoption hinges on technology acceptance, robust governance, and data quality – an essential step toward achieving the potential of predictive maintenance in aviation," Miret Mora concludes. **AI**