By James Careless

Predictive Engine Maintenance: Fix It Before It's Broke

"If it ain't broke, don't fix it" is a timeworn expression of maintenance common sense. However, this phrase was created before the concept of predictive engine maintenance was introduced. Now that predictive engine maintenance exists, aviation technicians can fix parts before they're broke.

What is Predictive Maintenance?

Let's start with a definition to set the context for this story. "Predictive maintenance is a modern strategy that uses real-time data, historical trends, machine learning and advanced analytics to predict when a component or system on an aircraft is likely to fail or require servicing," said Karine Lavoie-Tremblay, director of commercial engines digital transformation at Pratt & Whitney, an RTX business. "This allows airlines and operators to perform maintenance 'just in time', improving safety, reducing unscheduled downtime, minimizing costs and extending the life of parts."

"Predictive maintenance is the proactive approach to get ahead of the point of failure of an engine component, and to either repair or replace it so that an operator can keep flying their engines with minimal interruptions," added Dr. Christian Keller. (He oversees the engine trend monitoring program at MTU Maintenance.) "It can be broken down further into on-wing and in-shop predictive maintenance, depending on the workscope."

Karine Lavoie-Tremblay, Pratt & Whitney

MTU image.

The Evolution of Predictive Maintenance

The history of predictive engine maintenance began more than five decades ago. This was the time that airlines and manufacturers began collecting more structured maintenance data through early aircraft level health monitoring systems. Still, the insights provided by this data were pretty basic in nature, which is why MROs continued to focus on scheduled preventive maintenance.

"It wasn't until the digital age in the 2000s that engine health monitoring was introduced and engine OEMs began to offer these services," said Lavoie-Tremblay. "With the introduction and widespread adoption of big data, cloud computing and the Internet of Things, it has evolved to a more advanced state to enable real-time predictive capabilities. Today, we are using machine learning and cutting-edge analytics to bring predictive maintenance to the next level."

By moving from a preventive to a predictive maintenance model, MROs are now able to service aircraft engines on an individual basis based on their actual needs, rather than bringing them into the shop for scheduled appointments whether they need it or not. This is why "predictive maintenance has grown steadily over the years with increasing demand for proactive maintenance planning in order to keep engines on-wing for as long as possible," Dr. Keller said. However, "while the focus was initially on-wing predictive maintenance, recent market challenges, such as the drop in demand due to the pandemic, have increased the demand for maintenance planning optimization. Because of that, there is now an increased emphasis on the prediction and optimization in the scheduling of shop visit events to make them as cost effective as possible."

AI's Impact on Predictive Maintenance

Artificial intelligence (AI) is the game-changer of the current digital age, and it is having a big impact on predictive maintenance.

A case in point: "Pratt & Whitney is already utilizing artificial intelligence and machine learning to improve the design,

development and testing of products, making our systems smarter, easier to use and more capable than ever, with enhanced safety," said Lavoie-Tremblay. The company is currently developing and deploying advanced AI-enabled MRO capabilities via its Singapore and North America technology accelerators.

Here are three ways Pratt & Whitney (P&W) is using AI to enhance predictive maintenance. First, "engineers at our Singapore engine center, Eagle Services Asia, have developed a collaborative robot (cobot) to assist technicians to capture photo documentation of the engine's external components, showing the pre- and post-overhaul condition of an engine," Lavoie-Tremblay said. "This system replaces the routine photo-documentation task previously performed by technicians and elevates the skillset of the technicians to operate the system."

Next, in collaboration with the Indian start-up Awiros, P&W has launched "Percept," an AI-based tool for real-time aircraft engine inspections. This tool leverages computer vision and AI to speed up the inspection process, reducing the time taken by nearly 90% compared to traditional methods. It can be used in both pre- and post-lease inspections of aircraft engines.

Finally, P&W is using digital twins to visualize, animate and simulate the current and future operational state of a product cell or factory. "The software creates a digital model of the shop and sets important baseline targets for metrics such as TAT and throughput, enabling equipment and manpower optimization," said Lavoie-Tremblay.

MTU's Dr. Christian Keller says myEFM requires artificial intelligence to drive its algorithms. AI can be used to support the diagnosis of engine faults or knowledge management supported by large language models. MTU Aero Engines image.

MTU is also deeply involved in AI-enhanced engine maintenance. "As in other industries, artificial intelligence promises a revolution in how work is conducted and this is no different in predictive maintenance," Dr. Keller said. "Some of the recent prediction and optimization capabilities have only been made efficient enough by the use of AI. Where conventional methods sometimes struggle with long compute times or high compute resource requirements, AI and specifically machine learning help speed these up so they become manageable. MTU's myEFM requires artificial intelligence to drive its algorithms. Furthermore, AI can be used to support the work of experts, for instance, in the diagnosis of engine faults or knowledge management supported by large language models."

Anca Mihalache is the managing director of AERO CARE, a Romanian company focused on aircraft engines. She said that AERO CARE has yet to take the AI plunge. "I believe the future will show a greater reliance on AI for predictive maintenance, and maintenance in general," Mihalache observed. "But we are not quite there yet."

Anca Mihalache, AERO CARE

Predictive Maintenance Solutions

Now that we have considered the general evolution of predictive maintenance — and AI's increasing role in this approach — it is time to get specific about actual available solutions.

Pratt & Whitney has been evolving and enhancing its predictive engine maintenance programs for some time now. "Over the years as wireless technology and data storage technology improved, the ability for airlines to get full-flight data from the aircraft automatically has changed," explained Lavoie-Tremblay. "With the ease and convenience of newer technologies, we as the OEM are able to access this data much sooner and more regularly. This includes actual flight performance data and expected physics-based performance, along with some artificial intelligence and machine learning which provides trends, alerts and inspection recommendations."

As a company, (P&W) has put considerable effort into capturing operational data from their entire portfolio of engines, from the day each engine is made to its last day of service. This comprehensive database has allowed this firm to substantially advance the quality of its engine health management analysis. Moreover, P&W's ongoing investments in Industry 4.0 technologies has made it possible to capture, consolidate and automate the flow of product-related data from the design phase through manufacturing, delivery, maintenance, repair and overhaul.

As well, "Pratt & Whitney is running several key initiatives related to product-specific digital twins and the digital thread for the flow of connected data from Enterprise resource planning (ERP), product lifecycle management (PLM) and manufacturing execution system (MES) platforms," Lavoie-Tremblay told *Aviation Maintenance* magazine. "For our clients, Pratt & Whitney offers a range of solutions from data services to expert analysis of engine operational data. With the data digitally connected and centralized, engineers can have significantly better visibility into performance and wear of parts, potentially increasing engine availability and optimization of maintenance operations."

MTU's progress into predictive engine maintenance has been incorporated into the MRO's Engine Fleet Management (myEFM) and Engine Trend Monitoring (myETM) proprietary maintenance platforms. "Both of these services are available via our customer portal myMTU, which offers a range of additional

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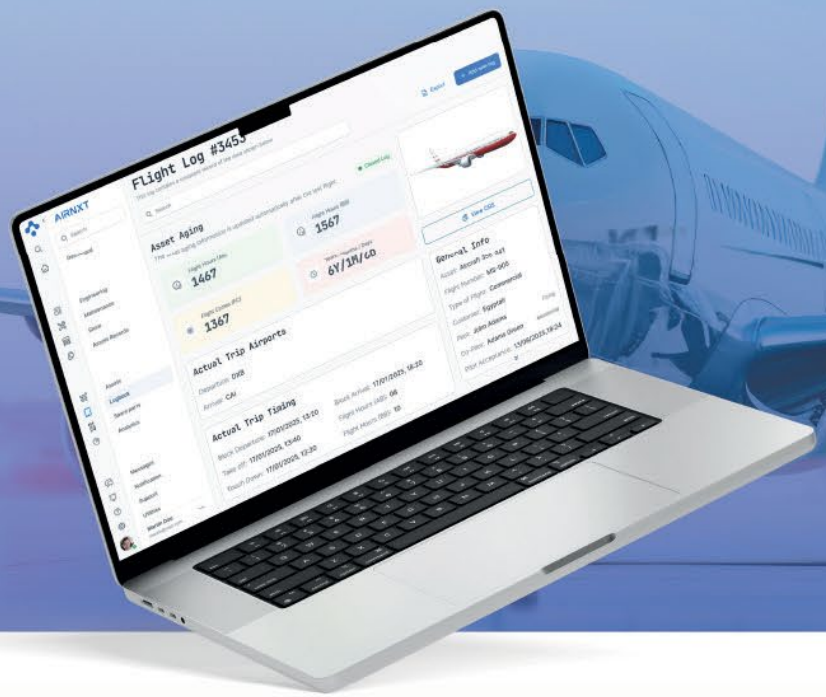

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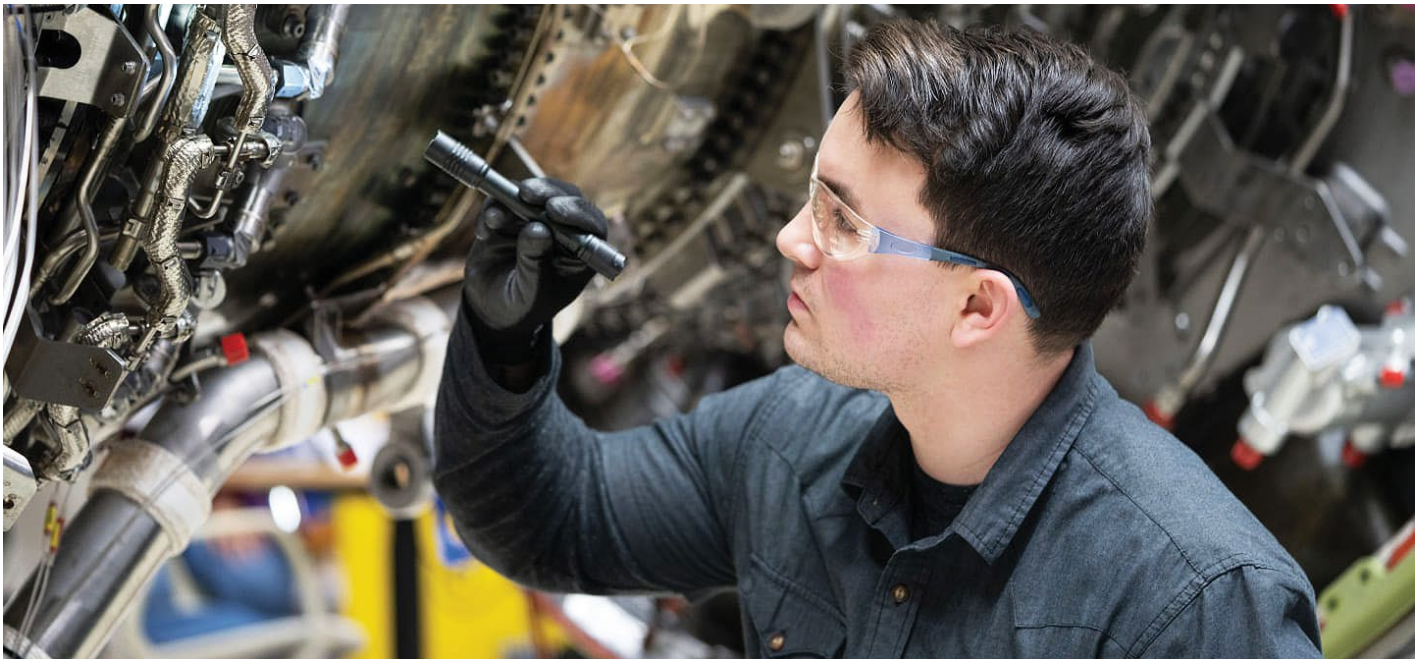

GE Aerospace says it is providing MROs with advanced AI-enhanced predictive maintenance tools that allow the MROs to forecast final work scopes and parts required for a repair months before an engine's induction date. GE Aerospace image.

applications supporting our customers' operations and engine maintenance," said Dr. Keller. "myEFM calculates optimal maintenance scenarios using a series of factors such as fleet composition, the engine's health and operational environment, cost structures of the operator, parts availability, and others. With the help of AI-powered algorithms, we calculate the optimal timing and workscope for a shop visit, which thus reduces overall operating cost and maximizes on-wing time. Meanwhile, myETM is geared towards on-wing performance monitoring and predictive maintenance. Triggered maintenance actions can typically be performed by line maintenance crews, with help from MTU's ON-SITEPlus service experts whenever our customers need

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Pictured here is the tip of a borescope that is part of an AI-enabled Blade Inspection Tool (BIT). GE Aerospace technicians use this to inspect critical jet engine parts. The AI guides the selection of part images to help technicians perform faster, more accurate inspections. BIT can be anchored into position to capture images of items like the high-pressure turbine blades during an on-wing inspection. The BIT counts and indexes each blade as it rotates into view, enabling technicians to compare and measure what they're seeing, determine whether a blade is serviceable or not, and troubleshoot potential issues. BIT has helped reduce processing time from 3 to 1.5 hours vs. a standard Borescope Inspection (BSI), the company says. GE Aeropace image.

specialized equipment or support."

GE Aerospace's fleet support teams are currently moving from condition-based to predictive-based maintenance. According to the company, this shift is enabling faster turnaround times (TATs) and enhanced time-on-wing (TOW) for its fleet of 49K+ commercial engines currently in service.

"For the past ten-plus years, we have been developing and applying AI technologies with great impact to support this revolutionary shift," said a GE Aerospace spokesperson. "Today, we're seeing 60% earlier lead times for identifying predictive maintenance measures, a 45% increase in detection rates, and a reduction in the number of false alerts in half over the past decade. Additionally, we have been able to expand the number of conditions that can be monitored 24/7 on our engines with greater accuracy and consistency."

GE Aerospace is providing MROs with advanced AI-enhanced predictive maintenance tools. These tools allow the MROs to forecast final work scopes and parts required for a repair months before an engine's induction date. "It's not unusual to see an escalation in the scope of work and what an engine ends up needing," the spokesperson said. "Using AI, we're able to foresee and plan for it so that our MRO shops are not caught off guard and don't incur any undue delays in repairing and returning an engine to service."

Long term, GE Aerospace is looking to enable the next big leap from predictive to more personalized maintenance, so that its MRO services can be tailored specifically to each airline customer's fleet. "With the rapid advancements we're seeing in AI and the development of a robust digital thread of data and analytics happening across our MRO value chain, we're developing the fundamental building blocks required to set up this next shift," said the spokesperson.

As for AERO CARE? According to Mihalache, her company supports predictive maintenance "by having in-stock parts ready to go, in my opinion, the biggest current problem is that the BER [beyond economical repair] rates are higher than ever and the risk of selling a unit to meet a TAT and then discovering it to be non-repairable is very high. As such, the shop visit of the engine gets delayed. Our approach to this problem is having an agreement with the repair shops for a shorter TAT which allows us to have a constant flow of parts. We are also trying, as much as possible, to keep modules in stock that we prefer to use as exchanges. It might end up a bit more expensive for the customer but the shorter turnaround time to have the engine back flying helps recoup the extra cost."

Predictive Maintenance That Stands Out

Aviation maintenance is a multi-billion-dollar business, with many vendors competing for clients. This is why we asked the companies interviewed for this story what makes their predictive maintenance platforms stand out.

We started with the engine manufacturer P&W. "Using Pratt & Whitney EngineWise Data by ADEM (advanced diagnostics and engine monitoring), we manage our customers' engine health and maintenance planning requirements, helping them achieve world-class reliability and controlled maintenance costs over the life of their engines," said Lavoie-Tremblay. "Through these services, we deliver greater insights on maintenance planning requirements, superior reliability and controlled maintenance costs over the life of more than 11,000 in-service engines for more than 140 customers. We have invested significantly in upgrades to ADEM to improve our ability to efficiently capture, store and analyze data from multiple sources."

Pratt & Whitney uses the Agile project development approach to collaborate, adapt and modify its service quickly to meet its customers' needs and support their fleets. As a result, "customers now have instant, global access to state-of-the-art visualization and analytics, including full-flight data capabilities, from any desktop or mobile device," Lavoie-Tremblay said. "With access to millions of data points per engine flight cycle, coupled with investments in data and analytical capabilities, we have improved our ability to get better insights into our engines' as-flown behaviors and communicate recommended actions to our customers from a turnaround of weeks to hours, with access to near real-time flight data and state-of-the-art analytics. This plays a critical role in the optimization of engine removal forecasts and the customer's fleet operational availability."

As for MTU Maintenance? "What sets MTU Maintenance apart is its more than 45 years of MRO experience on all types of engines, which, thanks to increasing digitalization, we can feed into our optimization algorithms," said Dr. Keller. "MTU Maintenance also draws upon technical knowledge and reinforces its MRO activities from OEM experience via our parent company MTU Aero Engines. The result is an unrivaled ability to tailor maintenance services to individual customer needs. Our tools and services are used by a wide range of customers. From small airlines that may need our specialized engineering support through myETM to large operators with hundreds of aircraft, which profit significantly from our holistic fleet management

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MTU's engine trend monitoring (myETM) is an intelligent tool for predictive maintenance planning and condition-based engine maintenance. It measures and monitors important engine parameters during flight. The insights it gains, coupled with empirical data, allow MTU to identify and resolve the first signs of engine wear early on, the company says. MTU Aero Engines image.

approach through myEFM."

From AERO CARE's perspective, what sets them apart from the competition is this company's focus on personalized customer service. "If we are talking about an airline, for example, we probably know details about the engine fleet and we expect a shop visit to happen in a certain quarter," Mihalache said. "As such, we will have stock, ready to go, of the units we know are most impacted for that particular type of engine and area of operations. If we are talking about an MRO customer, we know the number of shop visits expected for a type of engine and we either hold stock or we propose consignment agreements, with preapproved prices, to make the process as seamless as possible.

We are highly specialized in certain types of engines (CFM56 and CF6), and our experience helps to reduce TATs for our customers' shop visits. For the lessors, we do our best to have in stock, ready to go, the so-called 'hot parts' to help them save time and get their assets back in the air as quickly as possible."

What's Next in Predictive Maintenance

What will be the "Next Big Things" in predictive engine maintenance, and when will they arrive? That's a question we put to our experts. Here's what they told us.

"Since predictive maintenance is not a new topic, there will likely be a steady evolution with increased capabilities, possibly accompanied by regulation that allows more flexible maintenance intervals on more and more parts," said Dr. Keller. "AI will continue to be a useful tool and facilitate integration of diverse data sources to improve capabilities overall. We already have most of the tools and technologies ready, so I expect many future improvements to come from increased data availability and data sharing between operators and service providers."

"Increasing the connectivity of our digital thread across the entire product life cycle will enable real-time visibility into our products, optimizing our speed to respond to, and even predict our customer needs," Lavoie-Tremblay said. "We continue to build upon lessons learned, expand use cases and scale across the business to accelerate predictability and operational efficiency for our customers. As data quality is further refined and AI continues to advance, predictive maintenance models will move into the next phase to prescriptive and autonomous maintenance."


Pratt & Whitney image.

"I think once all the records of aircraft engines are digital (not scanned) we will see a big change in how we interpret the data — and for sure AI will be the one helping us with the results," said Mihalache. "For example, I think, just like in the medical field, results will be interpreted by the AI and tell us at part-out what non-repairable rate we can expect."

All told, the impressive results delivered by predictive maintenance today will likely be significantly more exceptional and far-reaching as digital technology advances. Granted, we may never see the day where unexpected engine failures cease entirely, but we will be much, much closer to achieving that goal in the years to come. AVM

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