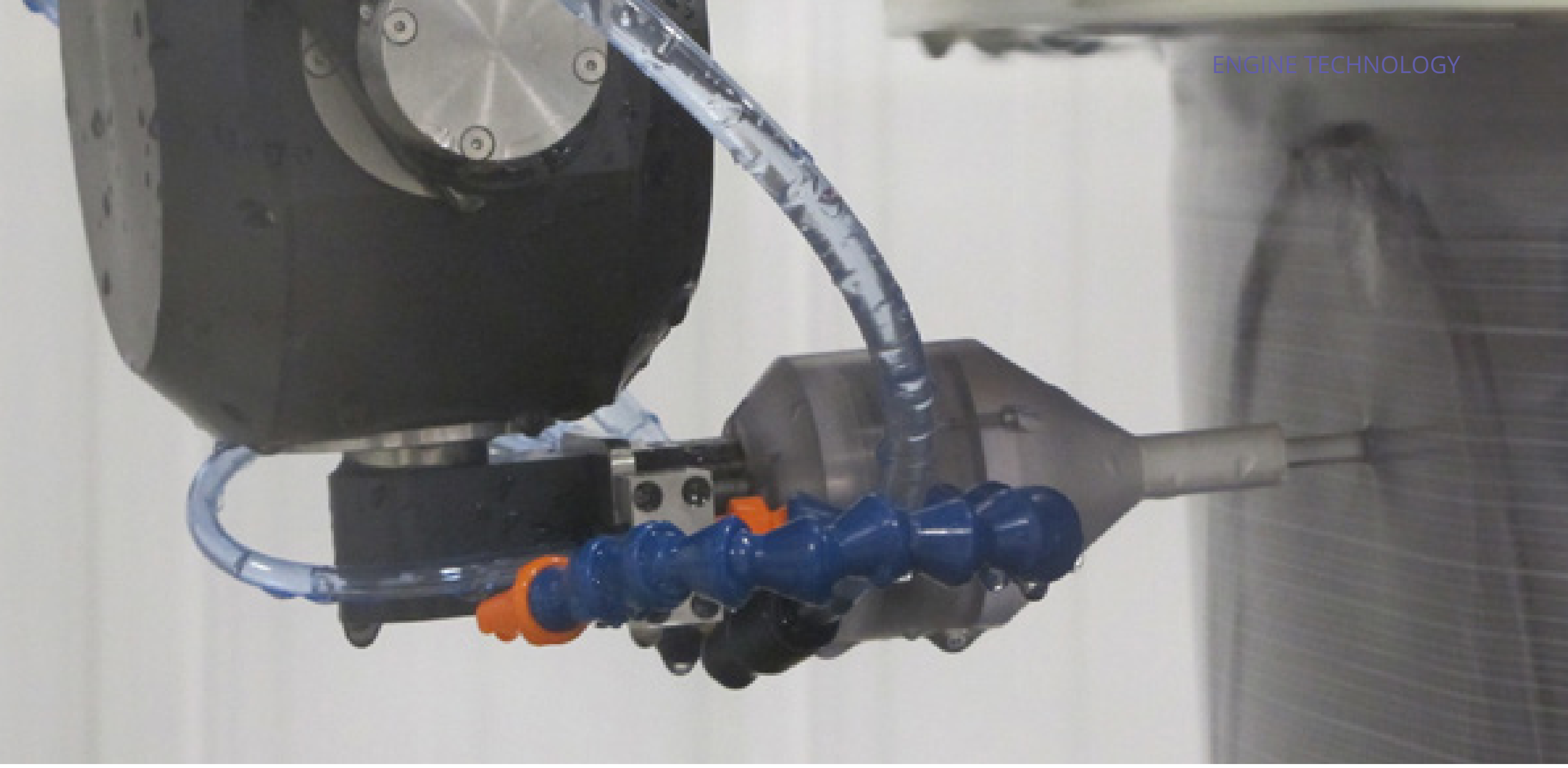


Advanced non-destructive testing

Non-destructive testing (NDT) is crucial to the verification of the integrity of engine components for both MRO providers and manufacturing companies. It provides MRO technicians and aerospace engineers with the appropriate input to perform quality control, root-cause failure analysis or component design optimisation. *Rene Sicard,* R&D manager at TecScan Systems, provides an update on the latest developments.

Aero-engine components require non-destructive testing (NDT) inspections to be performed at multiple stages during the manufacturing process, from raw material to finished product, as well as before and during MRO services. The NDT inspection techniques conducted on engine components are varied, but mainly encompass manual methods using visual inspection, digital X-ray, thermography, ultrasonic testing and eddy-current technologies. However, with new engine manufacturing processes such as laser welding, brazing and coating, many parts have become extremely complex to inspect before and after repairs.

At the same time, the arrival of new technology engines is making future quality control and MRO work an even greater challenge. New turbofans use exotic new composite materials in their construction and contain complex 3D-manufactured turbine blades. As a result, advanced automated NDT inspection technologies become important solutions where manual or conventional testing techniques are impractical or simply impossible. This article demonstrates some examples of these cases, in particular for automated testing of engine components such as compressor discs, engine bearings, turbine nozzles, fan blades and fan cases.

NDT OF ENGINE COMPONENTS

Aero-engines are composed of thousands of parts, each one designed and fabricated to sustain the stresses that exist at different portions of the engine. For example, fan blades in the intake are often made from titanium alloys for their higher resistance to impacts with birds and other debris, while turbine blades in the combustion chamber are fabricated from nickel-titanium alloys to sustain high temperatures. Blades, cases, compressor discs and bearings are all designed for performance and resistance to the conditions they are subjected to, and must be controlled accordingly.

Quality control occurs at different stages during the lifespan of an engine. Some controls are performed before parts attain their final shape. A good example is a compressor disc, which is typically controlled after pre-forming into a general shape, but before machining into its final form. Bearings are inspected at different stages of manufacturing, from dimensional controls to detection of the tiniest surface flaws on the rolling elements. The same applies to fan blades, which must be within tolerances in terms of weight, dimensions and defects. Newer models, such those that equip CFM's LEAP engines, are made of composite materials, which require additional controls for porosity and quality of bonding between the titanium alloy leading edge and the composite blade.

NDT OF COMPRESSOR DISCS

Many engine parts are forged discs or rings that are machined down to the proper shape. These include parts such as compressor discs and inner and outer bearing rings. Compressor discs need to be inspected at mid-manufacturing stage to detect flaws before expensive machining is performed. Non-destructive ultrasonic inspections are carried out on these parts to detect the tiniest flaws. Because pre-machined discs already have irregular and complex shapes, automated NDT systems with advanced inspection capabilities need to be used to inspect the disc from each side in order to identify flaws within such parts.

The challenges for this inspection technique arise from the part's geometry – or complexity – and its thickness variations. For this case, an automated system with advanced ultrasonic testing (UT) capabilities in immersion configuration is used to perform the disk inspection scans. Such a system is also equipped with a turntable and ultrasonic probe and operates in so-called 'ultrasonic pulse-echo mode'. Advanced software tools are also used for part programming, importing the 3D CAD drawings of the part, generating the scanning trajectories and completing the motion-controlled inspection scans. During testing, the turntable rotates the disc while the probe maintains a constant distance-angle, moving along the radius of the disc until the automated inspection is finished. During this operation, the system records the ultrasonic signals going through the disc volume and at the same time it compensates for any thickness variation.

MAIN SHAFT BEARINGS

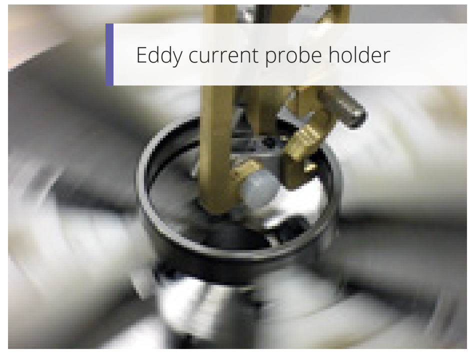
Hundreds of high-value bearings can be found on a typical aircraft. Among them, the main shaft bearing, located in the engine core, plays a crucial role. Multiple verifications are conducted to ensure the quality of such bearings: Metallurgical, dimensional and non-destructive tests need to be done before higher-value bearings can be put or returned to service.

The rolling surfaces of a bearing require particular attention. Dimensional or surface imperfections can lead to premature wear, while structural flaws can lead to catastrophic failures. The raceway of the inner and outer portions of the bearing as well as the rolling element (ball, roller) need to be inspected with great care. Visual testing, liquid penetrant, surface etching, and eddy current testing are among the tests typically performed to ensure serviceability. In addition, to detect the tiniest surface imperfections and cracks that may be present in the bearing raceways, eddy-current systems are required. In this case, an automated eddy-current system equipped with a relatively small eddy-current coil is used to cover the whole raceway surface. Again, the bearing is held on a turntable and rotated while the probe is being translated and/or rotated.

These inspections push the eddy-current testing technique to its limit, requiring test frequencies as high as 6 MHz to detect extremely small cracks. In such situations, maintaining an acceptable signal-to-noise ratio can become more challenging if the accuracy of the automated system does not allow control and retention of the proper probe orientation. While demagnetisation of the parts is essential to reduce the eddy-current signal noise level, reliable flaw detection can only be achieved by controlling the accuracy of the rotational speed and angular probe positioning, and by using a high-performance eddy-current instrument and probe.

Eddy-current surface inspections are also performed on the finished product of other forged disc components. Using the same scanner types as for the bearing raceways, some critical surfaces of compressor discs, nozzles and other parts found along the main shaft of the engine can also be inspected using the automated high-frequency eddy-current technique.


Automated eddy current system


Eddy current probe holder

"With new engine manufacturing processes such as laser welding, brazing and coating, many parts have become extremely complex to inspect before and after repairs."

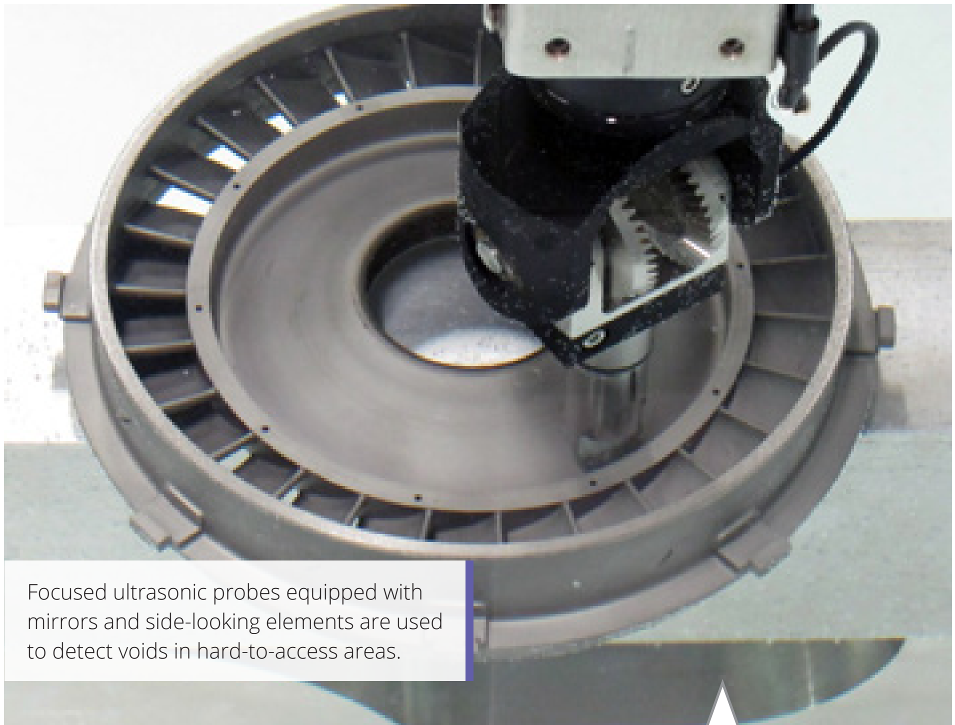
NOZZLE ASSEMBLY TESTING

The turbine nozzle is located at the turbine's combustion stage, where it is exposed to tremendous heat. This exposure could affect its integrity and create cracks in nozzle assemblies that are held by brazed joints. Whether it is at the production stage or after refurbishing of the nozzles by MRO companies, fractures and voids in brazing are known to pose a serious threat to flight safety and therefore need to be properly detected. These voids, resulting from a lack of fusion between the two brazed parts, are typically controlled using high-frequency ultrasound.

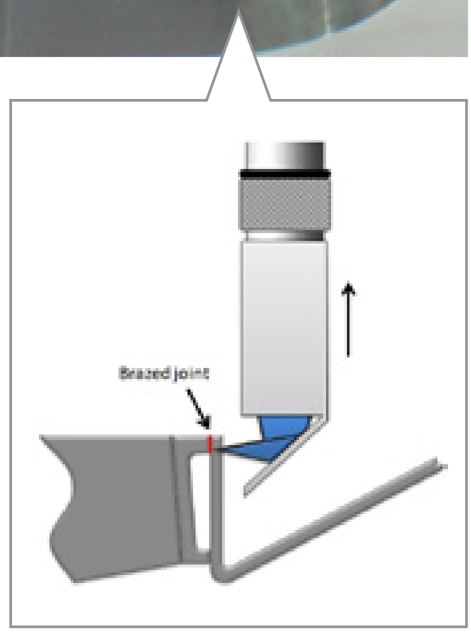
Brazed joint width, depth and accessibility within the part, as well as detection sensitivity, typically represent the major challenges of ultrasound inspection. Automated ultrasonic testing using high-precision immersion scanners equipped with high-frequency focused probes (15-25 MHz) are usually used to solve such problems. Because of the small void dimensions that need to be detected, high-resolution C-Scan images need to be produced by the automated system. Once again, the circular symmetry of the parts calls for the use of a high-precision turntable.

FAN BLADES AND FAN CASES OF NEW-GENERATION ENGINES

New generation jet engines use carbon-fibre composites for the construction of their fan blades and fan case modules. The LEAP engine from CFM International uses complex 3D-woven composites to fabricate its fan blades and fan case. Such a design solution provides several advantages: significant weight reduction; reduced fuel consumption; and improved engine durability. However, these new technology engines with integrated composite materials present specific challenges for conventional NDT inspection technologies. As the complexity of these engines increases, quality control and MRO services will rely increasingly on advanced automated NDT systems to perform repeatable and reliable testing. For such complex engine components, it is expected that MRO companies will work hand-in-hand with manufacturers to developed novel and highly automated inspection techniques that have not yet been included in the quality control manuals.



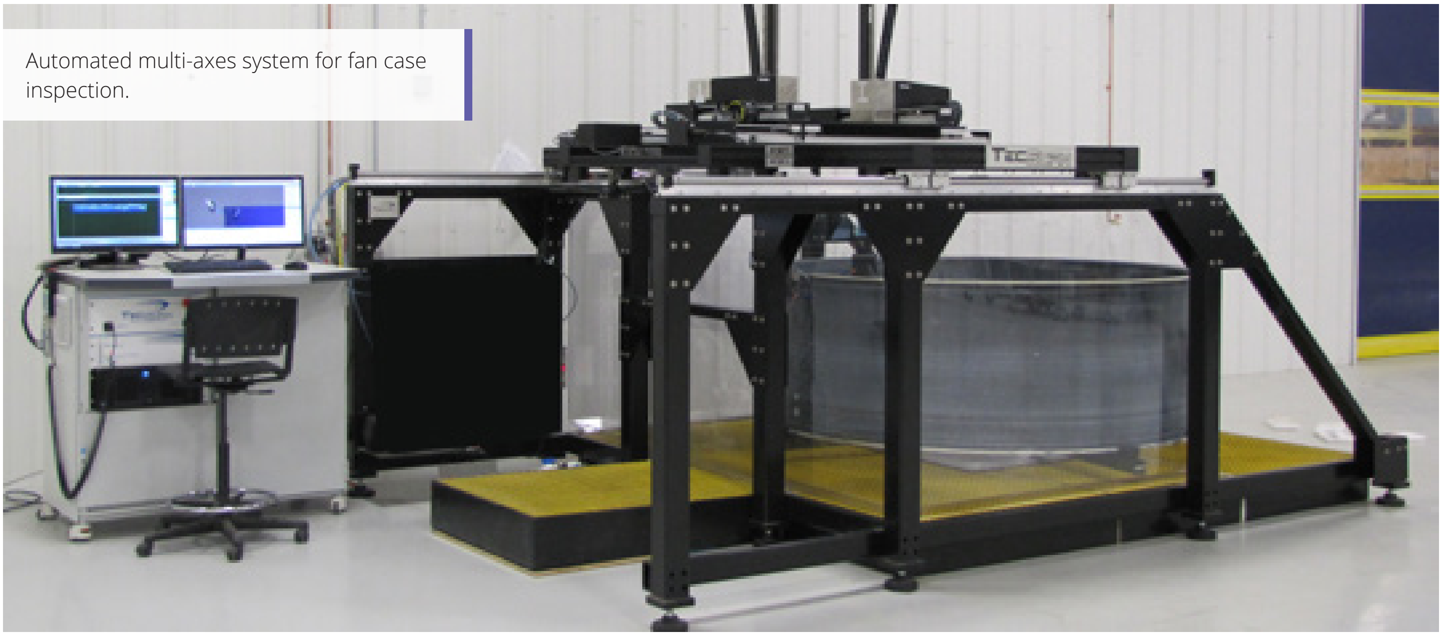
Focused ultrasonic probes equipped with mirrors and side-looking elements are used to detect voids in hard-to-access areas.



At the manufacturing stage, these engine components must be tested to detect various types of anomalies such as delaminations, porosities, foreign material and other types of defects that can affect part integrity. However, MRO services need to perform advanced quality tests before and after the repair and overhaul of these components.

For the inspection of fan blades and fan cases, higher-end automated and multi-axes ultrasonic testing systems are used in combination with an advanced motion control solution for complete 3D inspections. Such a solution allows the system's probe to move along the complex curvatures of the inspected part. Inspectors can import the CAD files of the inspected parts, perform 3D inspection and generate accurate C-Scan images for analysis and interpretation of the inspection results.

But, once again, this brings us back to the challenges when performing advanced non-destructive automated testing – where several requirements and parameters need to be controlled in very precise ways. One important requirement for reliable automated ultrasonic inspection is to maintain a constant probe angle during the entire inspection time. Another parameter is probe distance: the distance between the probe and the tested part.



Automated multi-axes system for fan case inspection.

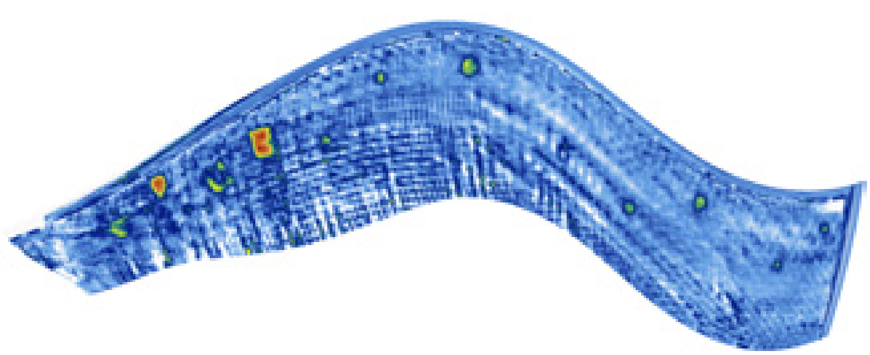
A common challenge for both blade and fan case testing is the variation of wave attenuation, a parameter used to characterise flaws in the material. Such variation naturally occurs due to part shape and thickness, and material type. Data interpretation must be adapted to these normal variations in order to perform overall part analysis and pinpoint flaws. This can either be done by performing analysis relative to some calibrated samples similar to the inspected parts, or by using more advanced signal processing tools that consider these variations to perform a global analysis.

Maintaining a proper signal-to-noise ratio during the automated inspection is also a challenge due to the composition or complexity of the part geometry. Again, advanced tools may be required in order to analyse all of a part on a single scan, otherwise multiple scans performed with different settings may be necessary.

The example presented demonstrates how a 3D-scanning solution and automated UT testing are being used to perform inspections of fan blades and fan cases. The below-left image shows an example of a C-scan result obtained on a sample composite fan blade containing disbonds. These were created with Teflon inserts between the layers of the composite blade. The C-scan result represents a colour-coded 3D presentation of the data collected during an automated inspection of the blade. The red spots on the C-scans represent the detected disbond defects. Similarly, the adjacent figure displays a C-scan with defects obtained from a tested engine fan case sample.

NDT has always and will continue to play an important role in the manufacturing stage and MRO of aero-engines. As the complexity of engine components evolves, so does the need for adapted automated NDT scanners. It is from a close partnership between aero-engine component manufacturers, MRO facilities and NDT equipment manufacturers that this objective can be attained. ■

C-Scan of sample engine fan blade



C-Scan of sample engine fan case