



Rust Never Sleeps

But now, neither
does your data

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Integrity Perspectives

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Editorial

Inspecting the Materials of Tomorrow

I remember the first time I stood next to a pipeline that had just been opened up for inspection. The crew had cut into a section that, from the outside, looked perfectly fine. No visible rust, no warning signs, no drama. But when they pulled that spool out and held it up to the light, the inside told a completely different story. It was quietly, invisibly, eating itself alive.

That moment stuck with me. Because it perfectly captures what this industry is really about, the things you cannot see are almost always the things that matter most. And that feeling never really goes away.

The failures that matter most rarely announce themselves. They build quietly, in places that are inconvenient to check, over timelines that outlast attention spans. That's the nature of what we deal with. And yet here we are. Still inspecting. Still finding better ways to look harder, reach further, and catch more.

There's no glamour in corrosion detection. Nobody's making blockbuster films about pipeline integrity assessments. But the work matters enormously, and the people doing it know that better than anyone.

What struck me most while putting this edition together was how much the conversation around risk is evolving. It's no longer just about finding damage; it's about anticipating it.

And then there's the question of who's going to be doing all of this ten years from now. The workforce challenge is real. But some genuinely exciting ideas are emerging — and you'll find them here too.

So grab a coffee, find a quiet corner.

This one's worth reading slowly.

Santosh Gavankar
Editor-in-chief

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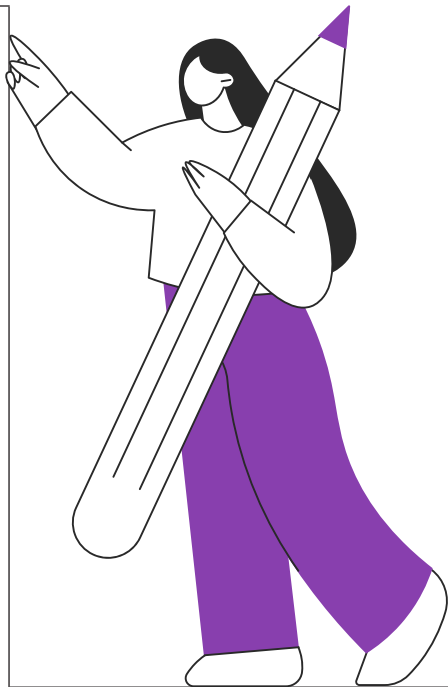
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That's why we created **NDT Talks** — a monthly panel where real experts share insights you won't find online.



Top Stories

Insights in Focus

*Top Stories Shaping
the NDT Industry*



Baker Hughes to Sell Waygate Technologies to Hexagon in \$1.45 Billion Deal



Image Source - @Reuters

Baker Hughes has announced an agreement to sell its Waygate Technologies business to Hexagon in an all-cash transaction valued at approximately \$1.45 billion, subject to customary closing adjustments.

Waygate Technologies, part of Baker Hughes’ Industrial & Energy Technology (IET) segment, is a global provider of advanced nondestructive evaluation solutions used for the inspection of critical assets without operational disruption. The transaction includes the full portfolio of remote visual inspection, ultrasonic testing, radiography, and industrial imaging technologies, along with associated intellectual property, operational footprint, and resources.

The divestiture reflects Baker Hughes’ ongoing portfolio optimisation strategy, following three recently completed transactions and alongside its pending acquisition of Chart Industries. The company stated that these actions are aimed at strengthening earnings durability, improving cash flow, and reinforcing its balance sheet through disciplined capital allocation.

“This transaction marks another significant milestone and reinforces our ongoing commitment to long-term value creation for our shareholders,” said Lorenzo Simonelli. “By sharpening our focus on our core strengths – rotating equipment, flow control, digital, production optimization and decarbonization – we are strategically positioning Baker Hughes to deliver higher returns while accelerating investment in high-growth areas that are aligned with our long-term vision.”

Hexagon, headquartered in Stockholm, operates across 50 countries with approximately 24,500 employees. The company specialises in precision measurement, positioning, and autonomous solutions, supporting industries such as aerospace and defence, automotive, construction, manufacturing, and mining. The acquisition of Waygate Technologies expands its capabilities in nondestructive evaluation and industrial inspection technologies.

The transaction is subject to regulatory approvals and other customary conditions, and is expected to close in the second half of 2026.

TSC Subsea Deploys ORCA for In-Service Hull Inspection



Image Source - © Copyright TSC Subsea

TSC Subsea has introduced its ORCA system for in-service hull inspection, marking a development in non-destructive testing (NDT) capabilities for the marine and offshore sectors.

The deck-launched crawler enables inspection and condition assessment of vessel hulls both above and below the waterline while assets remain operational. The approach is designed to support continuous vessel availability by reducing reliance on dry-docking and minimizing operational disruption.

ORCA is built on TSC Subsea’s proprietary Acoustic Resonance Technology (ART), which has been validated by Lloyd’s Register for quantitative ultrasonic thickness measurement (UTM). The system is capable of detecting both internal and external corrosion in ship hull carbon steel

plates through coatings, eliminating the need for surface preparation or coating removal.

The system has undergone engineering development, testing, and industry engagement, including demonstrations with international naval stakeholders and a completed in-water inspection of an FPSO hull. These deployments focused on improving inspection efficiency while addressing challenges such as dry-docking requirements, diver exposure, and data consistency.

ORCA’s omnidirectional drive system enables high coverage and maneuverability across complex hull geometries, reducing the number of deployments required for comprehensive inspection. The platform delivers wall thickness measurements with sub-millimetre accuracy, supporting repeatable and reliable data collection for integrity assessment.

From an NDT perspective, the system enables full hull inspections without taking vessels out of service. Its diverless, deck-launched deployment reduces safety risks and inspection costs by removing the need for divers, remotely operated vehicles, or dedicated support vessels.

The inspection data generated by ORCA is intended to support risk-based inspection (RBI) programmes, providing asset owners and operators with consistent inputs for maintenance planning and structural integrity management.

With commercial availability now extended globally, the system is positioned for deployment across naval fleets, commercial shipping, and offshore production assets, including FPSOs, where continuous operation and asset reliability remain critical.

Pro-Surve Acquisition Strengthens PK's Inspection Technology Portfolio



Image Source - @pktechnology



Companies has announced the acquisition of Pro-Surve Technical Services, strengthening its position in the U.S. inspection and non-destructive testing (NDT) market while expanding its national service capabilities.

The acquisition integrates Pro-Surve's expertise in technical inspection, asset integrity, and compliance solutions into PK's Technology & Inspection Services business unit. The move reflects continued consolidation within the inspection sector as companies seek to enhance service portfolios, geographic reach, and technology integration.

Founded more than 13 years ago, Pro-Surve has developed a reputation for delivering inspection and compliance services through experienced technical teams and established quality

standards. The integration is expected to enhance PK's ability to deliver inspection, NDT, and compliance services across industrial and energy sectors in the United States.

"We're delighted to welcome the team at Pro-Surve to the PK family! This is a major milestone. Together we are expanding our reach and delivering an even broader range of high-quality inspection services to our customers. This partnership strengthens our capabilities and allows us to offer a more comprehensive suite of solutions." said Stewart Records.

Pro-Surve's leadership also highlighted the alignment between the two organizations and the potential for expanded technical capabilities.

"This integration brings to life an idea first envisioned in 2019 and now fully realized in 2026. The shared culture, dedication, and care demonstrated by employees from both organizations will significantly strengthen and expand the value of our combined solutions for our clients. We are especially optimistic about the synergy created by uniting a highly knowledgeable team with an exceptional suite of software solutions. Together, these strengths position us to deliver even greater impact moving forward. I truly believe the best is yet to come." said James Cesarini.

The transaction is supported by DC Capital Partners, which emphasized continuity in client service alongside expanded capabilities.

"Great client service is what matters most. Both PK and Pro-Surve have earned the trust of their clients by consistently delivering high-quality service. By bringing these businesses together, clients will continue to receive the service they already know and value, now backed by broader capabilities, greater geographic reach, and even more resources." said Tom Campbell.

"In addition to their core inspection and technical services, both PK and Pro-Surve excel through their differentiated intelliSPEC and ProVision technology solutions. Together, the combined business will be able to dedicate greater resources to enhance the next generation of this technology to enable true best-in-class service." said Jack Goldstein.

The combined entity will continue to deliver uninterrupted services during the transition period, with an expanded portfolio of inspection technologies and digital solutions. The integration of proprietary platforms such as intelliSPEC and ProVision is expected to further support data-driven inspection, asset integrity management, and compliance workflows across industrial operations.

The development underscores a broader trend within the NDT and inspection sector, where companies are combining technical expertise with digital tools to deliver more comprehensive and scalable inspection solutions.





Cover Story

The Silent Enemy Beneath the Surface

Corrosion has always been there. The question is whether we're finally ready to stay ahead of it.

Cover Story

A maintenance crew on a routine dry-dock job cuts open a section of pipeline on a vessel that has been running without any major complaints for years. No alarms. No pressure drops significant enough to flag. No reason, really, to expect anything out of the ordinary.

But when they pull that section out and lay it on the ground, they stop. They look at each other. And then they look back at the pipe.

The outside is fine. Completely fine. But the inside? Layers of corrosion products built up over years. Nodular deposits projecting inward from the walls. Pitting so aggressive that the effective diameter of the pipe had shrunk to nearly half of what it was originally designed to be. The pipe wasn't just corroding. It had been quietly compromising its own integrity for years, and nobody knew.

That story isn't unique. Versions of it play out across terminals, refineries, vessels, and processing plants all over the world, more regularly than the industry likes to acknowledge.

The Enemy You Can't See

What makes corrosion so uniquely difficult to manage is that it doesn't look like a crisis until it already is one.

A crack in a structure is visible. A leak announces itself. Significant mechanical damage leaves marks that a trained eye can find. But internal corrosion operates entirely out of sight. It works within pipe walls, beneath insulation, under deposits, in the stagnant corners of systems where fluid movement is minimal and inspection access is limited.

And it is extraordinarily patient.

It doesn't require a catastrophic trigger to get started. It needs the right conditions, a little moisture, a shift in chemistry, an environment that favors electrochemical activity, and then it simply gets to work. Slowly at first, then progressively, compounding on itself, using its own byproducts to create increasingly aggressive local environments beneath the surface.

By the time it appears on an inspection report, it has usually been developing for a very long time.

The Way We've Been Fighting It

For a long time, the industry's response to corrosion was built around a straightforward model. Inspect on a fixed schedule. Replace what shows visible wear. Respond to what fails. For an earlier era of infrastructure management, that approach was reasonable. Systems were newer, risk profiles were less complex, and the available tools didn't offer much beyond periodic checks anyway.

But that model carries a fundamental limitation.

It treats every section of a pipeline as roughly equivalent. A pipe running through aggressive soil near a flange connection, where flow turbulence accelerates deposit buildup and localized corrosion cells quietly develop, receives the same inspection attention as a stable, low-risk section running through benign conditions. The risk profile of those two sections is not remotely comparable. Yet the inspection program often doesn't reflect that difference.

The consequence is predictable. Resources are distributed evenly across a system, which in practice means high-risk areas are not receiving the focused attention they require. And that is precisely where integrity events tend to originate.

The industry has recognized this. The shift toward risk-based inspection, evaluating both the probability of failure and the consequence of failure for each segment of a system, represents one of the most meaningful changes in pipeline integrity management in recent decades. It redirects effort to where it genuinely matters, and it forces a level of analytical rigor that fixed-interval programs simply don't demand.

That shift is not always easy to implement. It requires good data, disciplined processes, and a willingness to revisit programs that have been running unchanged for years. But the results, in terms of both safety outcomes and resource efficiency, speak for themselves.

The Tools Are Catching Up

The strategic evolution is being matched by a parallel advancement in inspection capability.

Phased array ultrasonic systems now offer weld zone coverage with a resolution and efficiency that conventional methods cannot match. Guided wave testing allows inspectors to screen extended lengths of buried or insulated pipeline from a single access point, significantly reducing the need for excavation or insulation removal. Intelligent inline inspection tools travel through operational pipelines, collecting high-resolution data on wall thickness, geometry, and defect characteristics across entire networks without requiring a system shutdown.

Increasingly, the data collected through these methods

feeds into integrity management platforms that do more than simply store results. They track corrosion progression over time, identify locations deteriorating beyond expected rates, and support predictive assessments of where integrity risks are likely to emerge next.

That represents a meaningful shift in how pipeline operators relate to their own infrastructure. The system is beginning to communicate its condition in ways that allow for earlier, more targeted intervention.

But the Tools Are Only Part of the Picture

For all the progress in technology and methodology, one element remains irreplaceable.

The inspector standing in front of the pipe.

The professional who understands what a particular damage morphology indicates. Who can assess a corrosion pattern and draw conclusions not just about what happened, but about the underlying mechanism and what is likely to follow if conditions remain unchanged. Who brings field experience to a situation that data alone cannot fully interpret.

That expertise is built over careers, not courses. And right now, a significant generation of professionals who carry that

depth of knowledge are approaching retirement. The transfer of that experience to the next generation is one of the most pressing challenges facing the inspection community, and one that doesn't receive the same attention as technology investment or regulatory compliance.

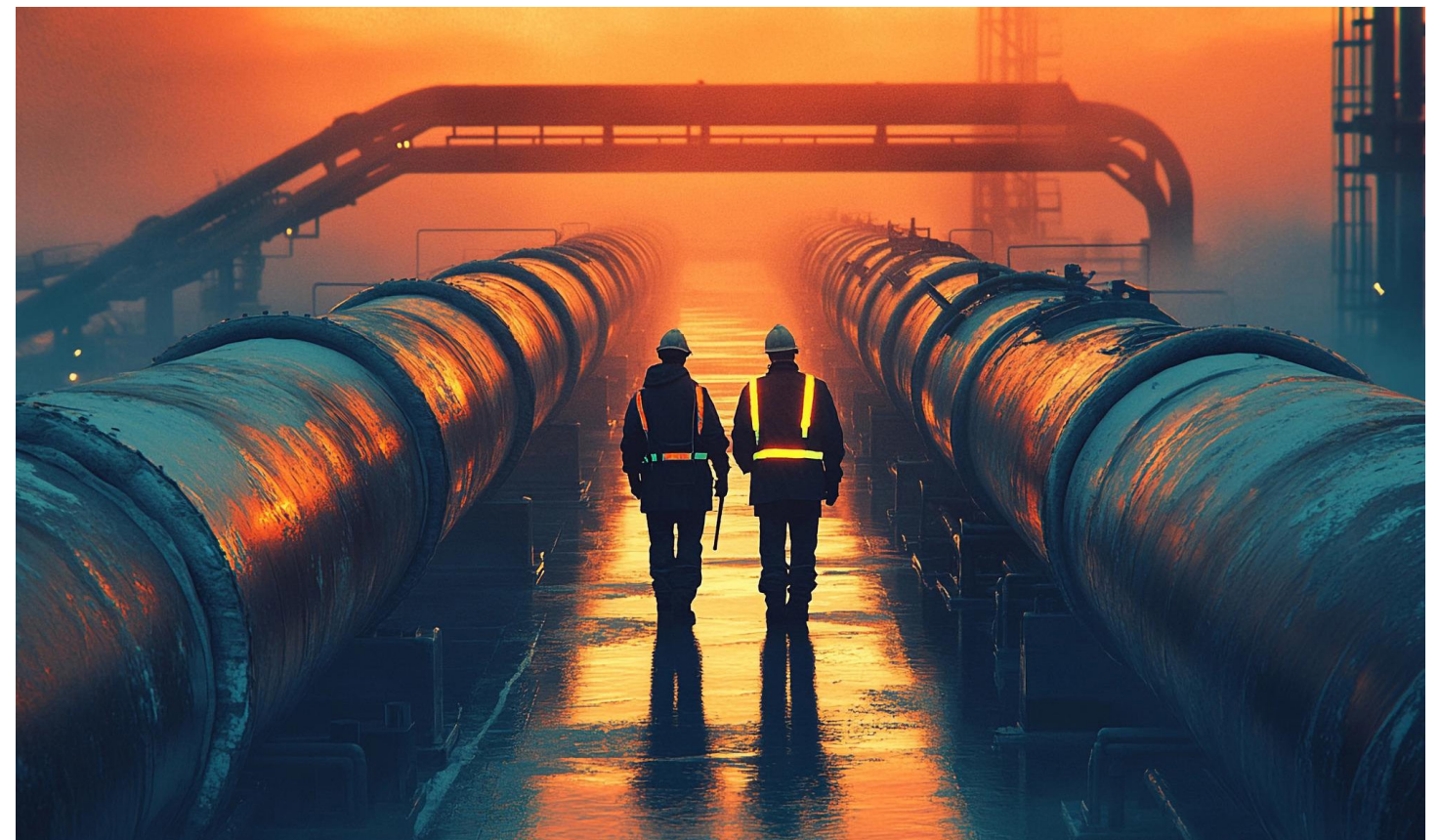
The tools are advancing. The frameworks are improving. But the workforce pipeline requires just as much deliberate attention as the physical infrastructure it is meant to protect.

Where This is All Heading

Corrosion will not be eliminated. That is not a failure of the industry; it is a material reality. As long as metal infrastructure operates in the presence of moisture, oxygen, and electrochemical gradients, degradation will occur.

But the story of this industry, right now, is one of a closing gap. The gap between corrosion occurring and corrosion being detected. Between failure happening and failure being anticipated. Between hard-won field knowledge residing in a generation of experienced professionals and being meaningfully transferred to the people who will carry this work forward.

Progress on all of those fronts is real and it is accelerating. The silent enemy beneath the surface isn't going anywhere. But then again, neither are we.



Training the Next Generation of Inspectors with Virtual Reality

Training inspectors through VR simulations to build skills before entering real environments.



Daniel Hoke

Quality Assurance Inspection Leader/ Owner,
A Better Inspector



Virtual Training

For years, training in the inspection world has followed the same pattern. A classroom, a stack of code books, and eventually a trip out to the field. That process works, but it has limitations. Some equipment is too large to bring into a training environment realistically. Some inspection scenarios are too dangerous to simulate in person. And sometimes the barrier to entry for new inspectors is simply getting hands-on time with the tools.

Virtual Reality is starting to change that.

Over the past few years, I've been building VR training environments focused on two major areas of inspection: Nondestructive Testing (NDT) and API inspection training. The goal is not to replace traditional training, but to fill the gaps where it struggles.

What surprised me most while developing these systems is how accessible the technology actually is.

One of the best demonstrations of that came from my own kids.

- Daniel Hoke

My 11-year-old has been running through the NDT simulations. In VR, he performs common inspection methods like Ultrasonic Testing (UT), Magnetic Particle Testing (MT), Penetrant Testing (PT), Radiography (RT), Real-Time

Radiography (RTR), Visual Testing (VT), and Positive Material Identification (PMI). These are real procedures inspectors perform every day in refineries, plants, and fabrication shops.

The interesting part is that when people see a kid performing these inspections in VR, the reaction is usually the same: "Wait... he can actually do that?"

And the answer is yes.

The simulations walk the user through the process step by step. A UT probe can be placed on a weld, and the waveform appears exactly like it would on a real instrument. Magnetic particle testing requires spraying particles and correctly positioning the yoke. Dye-penetrant inspections follow the same developer and dwell-time logic that inspectors learn in the field. The idea is not that an 11-year-old should be certified tomorrow. The point is that if a child can understand the workflow inside a VR simulation, then a new technician entering the industry can

learn it much faster as well.

Even my 3-year-old daughter was able to interact with the API side of the system. She put on the VR headset and began marking corrosion locations on a pressure vessel model. Obviously, she isn't calculating corrosion rates or referencing API 510 code requirements yet, but the interaction shows something important: the environment is intuitive. That leads to the second major focus area - API inspection training.

Unlike many NDT certifications, API certifications do not include a hands-on practical exam. There are good reasons for that. It is simply not practical to bring an entire pressure vessel, tower, tank, or heat exchanger into an exam environment. Even if it were possible, the liability and logistics would make it unrealistic.

So most API testing focuses heavily on code knowledge and written examination. But inspection is still a visual and analytical profession. Inspectors must recognize damage mechanisms, understand where to measure thickness, and identify

non-conformances in the field. Those skills are normally developed only after years of experience.

VR offers a way to simulate that experience safely.

Inside a VR training environment, a student can walk around a virtual refinery unit. They can inspect pressure vessels, piping circuits, tanks, and structural components. Corrosion, erosion, cracking, and mechanical damage can occur throughout the environment. Instead of looking at a picture in a book, the trainee can physically walk up to the equipment, crouch down, and measure the damage.

A UT thickness reading can be taken on a corroded shell section. A pit can be measured. A crack indication can be located. A corrosion area can be marked for further review.

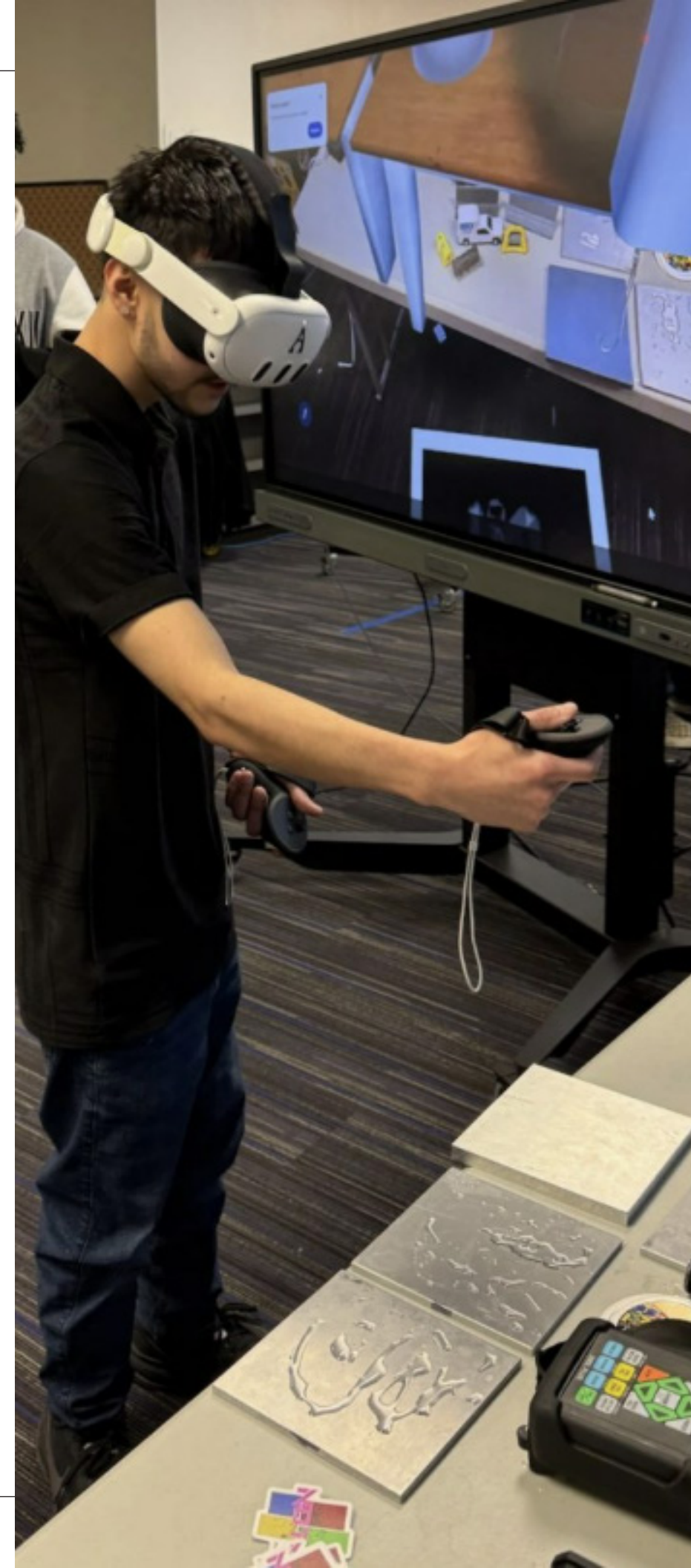
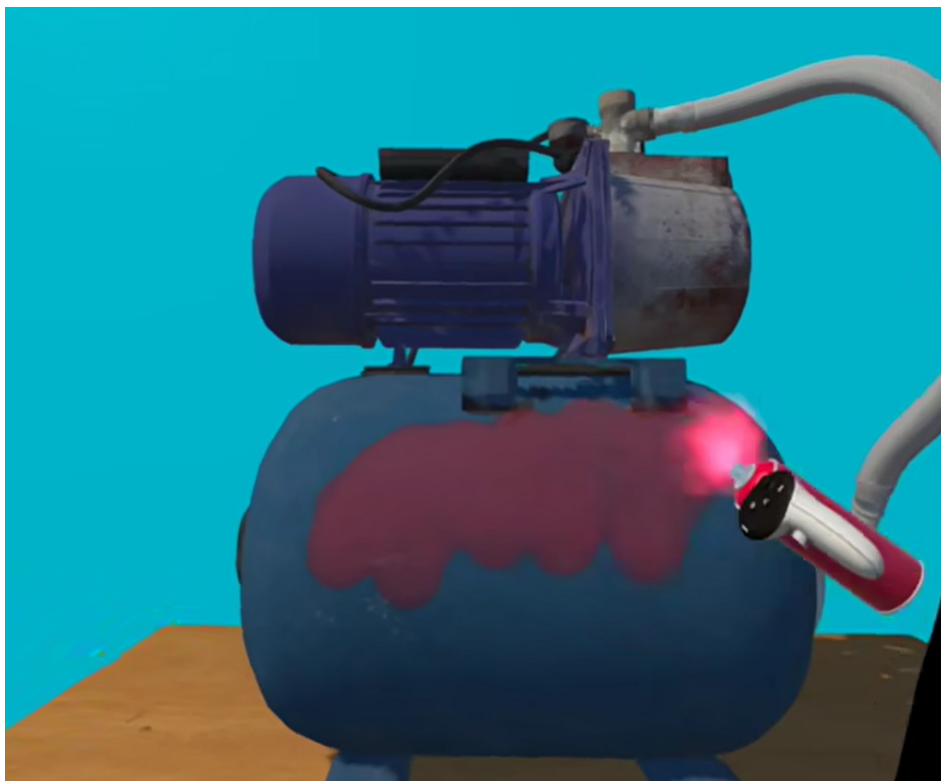
The system records those actions and sends the data to a laptop, where the inspection report can be written and reviewed. That information can also be used to build a scoring system similar to an Industry Sector Qualification (ISQ) style exam.

- Imagine a trainee entering a virtual plant and being asked to inspect a vessel.
- They must identify the correct damage areas.
- They must measure the thickness correctly.
- They must determine whether the equipment is acceptable for service.
- Every decision can be tracked and graded.

Before that person ever sets foot inside a real facility gate, you already know whether they understand what they are doing. That is where VR training becomes extremely valuable. It allows instructors to create scenarios that would normally be impossible to replicate.

Severe corrosion under insulation, internal erosion in piping, poorly installed pressure relief valves, missing nameplates, and incorrect nozzle repairs - all of these situations can be recreated in a controlled environment.

Students can make mistakes without consequences. In the real world, a missed indication can lead to major failures or safety incidents. In VR, a missed indication becomes a teaching moment.



Another benefit is accessibility. Training equipment can be expensive and difficult to share between schools and companies. A VR environment can replicate many different inspection tools and scenarios in one place. With a headset and a laptop, a training program can expose students to a wide variety of inspections without needing an entire shop full of equipment. For industries like oil and gas, petrochemical, and power generation, that kind of flexibility opens new possibilities for workforce development.

It also helps bring new people into the field. The inspection industry is facing a generational shift. Many experienced inspectors are nearing

retirement, and younger workers are entering a world that looks very different from the one their mentors started in. Digital tools, data integration, and advanced analytics are becoming part of everyday inspection work. VR training helps bridge that transition.

It introduces modern technology while still teaching the fundamentals that inspectors rely on: observation, measurement, and critical thinking. And if an 11-year-old can learn the workflow of UT or MT inside a virtual environment, it proves something important about the future of training.

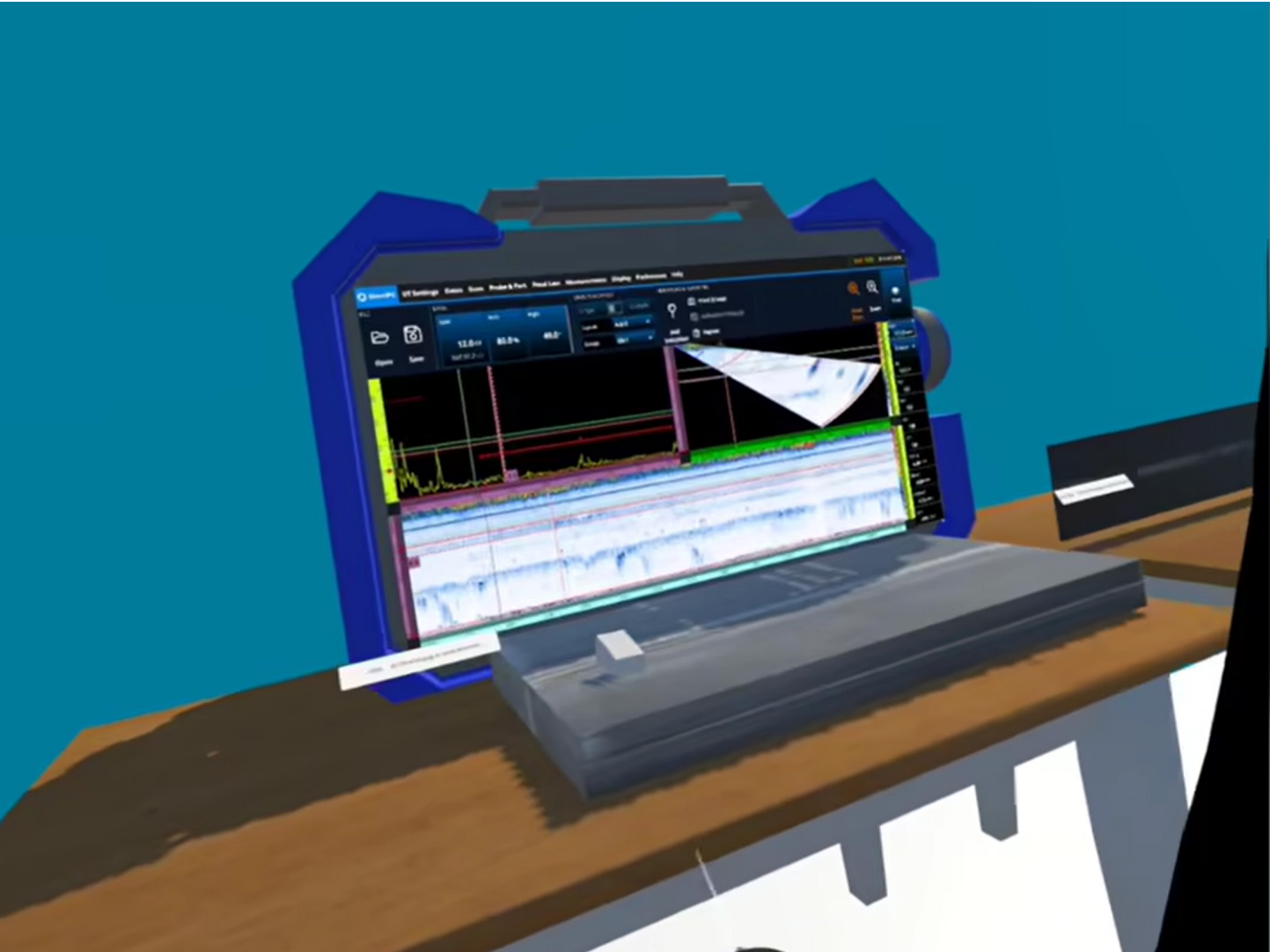
The next generation of inspectors may begin their careers in a virtual plant before they ever step into a real

one. That may sound unusual today, but so did many technologies that are now standard in our industry.

Virtual Reality will not replace field experience, and it should not try to. But it can better prepare inspectors, reduce training barriers, and enable organizations to evaluate skills in ways never before possible.

And sometimes the best way to demonstrate that potential is simple. Hand the headset to a kid.

If they can learn the basics of inspection in a few minutes, imagine what a dedicated trainee can accomplish with the same technology.



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Service Spotlight

Securing operational readiness across industries with Maintenance in Operational Conditions (MOC)

Reduce operational risk with smart maintenance of critical inspection equipment systems.



In

an era of escalating supply chain and labor pressures, the health of critical inspection equipment has become key to mitigate operational risk. Testia, an Airbus company, has developed a state-of-the-art service to maintain inspection tools, turning a logistical burden into a competitive advantage that contributes to improving safety and reliability across the entire industrial lifecycle.

The invisible chokepoint: managing risk in a constrained ecosystem

Modern industry is a story of meticulous precision and relentless reliability. However, in a highly regulated environment, even a seemingly minor issue can trigger a series of consequences with far-reaching effects. Across the global manufacturing & maintenance sectors, organizations are grappling with a complex set of systemic challenges. While industries are projecting steady growth through the next decade, this is accompanied by significant pressures, including chronic labor shortages, rising material costs, and persistent supply chain delays.

It is within this context that the readiness of critical inspection equipment emerges as a profound point of operational vulnerability. While a halted production line or a delayed infrastructure inspection due to an uncalibrated eddy current flaw detector or a broken ultrasonic testing device may appear to be an isolated logistical problem, it is a direct symptom of these larger, industry-wide bottlenecks. The time and effort an organization must expend to source a part, ship a tool to an OEM for repair, or navigate the complex logistics of calibration, becomes a drain on resources and a source of expensive downtime. Managing equipment health is no longer a simple administrative task, it is a strategic imperative.

The cross-industry risk of equipment failure

The risk is not merely financial. Any use of non-calibrated and unverified equipment in a highly regulated environment is a direct threat to the safety of the entire industrial chain. NDT equipment and inspection equipment in general, are the frontline tools for ensuring structural integrity, from the very beginning of the supply chain to the end of an asset's service life. They are used to inspect critical elements, from raw materials to finished goods. A discontinuity missed during a manufacturing inspection or a fatigue crack overlooked during a routine maintenance check can have catastrophic implications.

A Philosophy forged in aerospace, applied everywhere

At Testia, an Airbus company with over 30 years of experience, the foundational mission has always been "We Make Flying Safe". Today, this uncompromising aerospace standard is brought to every industry. Testia's Maintenance in Operational Conditions (MOC) service is a tangible extension of this philosophy. By ensuring that every piece of structural integrity equipment is always ready, verified, and calibrated, Testia actively eliminates a key point of failure in the safety chain and a pain-point of its customers.

The value proposition of MOC goes far beyond simple operational efficiency. It is a proactive solution that addresses the very real risk posed by faulty or unverified equipment. As David Rottembourg, CEO of Testia, states, "MOC should not be the core business of our customers - it's ours". This observation captures the essence of a proven business strategy: outsourcing non-value-adding activities to experts. This mission-critical service removes the logistical burden from the customer, allowing their highly skilled inspectors to concentrate on detecting anomalies and ensuring structural integrity. By taking on this responsibility, Testia directly contributes to the safety and reliability of our industries.



A Holistic Service Across the Lifecycle

Testia's MOC service is an end-to-end solution designed to ensure equipment readiness across manufacturing, assembly, and field maintenance.

The journey begins long before a tool is even purchased. Testia's technical advisory team works closely with customers to identify the most suitable inspection method and the right tool for their specific needs, leveraging deep knowledge of various device manufacturers. They then manage the procurement and logistics to secure the right equipment at the best possible price. For international partners, Testia goes a step further by translating technical manuals, ensuring every user has the information they need to operate the equipment effectively.

At the heart of the MOC service is a rigorous maintenance program overseen from a cutting-edge facility in Toulouse, France. A dedicated team of over 20 experts—including specialists in inspection methods, maintenance, logistics, and purchasing—proactively ensures the readiness of every device. Their vigilance extends beyond reported faults. Each tool undergoes a thorough diagnosis upon arrival to prevent future failures. The service includes fully managing the entire maintenance schedule for each inspection device, including calibration due dates. Depending on the device and the customer's needs, maintenance can be performed on-site or off-site. Testia can also provide temporary replacements for inspection devices during turnaround time to ensure operational continuity.

Another critical component of this service is its expertise in obsolescence management. When spare parts are no longer available, Testia can create a customized usage plan to extend the lifecycle of older equipment, safeguarding a customer's investment and operational continuity. A technical hotline provides continuous support, offering expert guidance for everything, from a quick question about method selection to assistance with device calibration.

This end-to-end model directly addresses the fragmented and unpredictable nature of the current supply chain. Testia acts as a single point of contact, insulating its customers from long lead times, inconsistent supplier performance, and inventory pressure plaguing the industry. It should be noted that customers can also book parts of the service however it fits their needs.

The company's ability to manage the entire lifecycle of a device — from purchase to obsolescence to resale — ensures that customers' equipment is always available and ready to use, minimizing costly downtime. This is further reinforced by a fixed-price structure that provides cost certainty in an inflationary market.

Expertise and innovation as key components

Testia's MOC service is built on a foundation of over thirty-year expertise in structural integrity and NDT. This deep knowledge, acquired through decades of providing NDT training and inspection services, ensures they offer unparalleled advice and support.

Testia began its MOC journey 15 years ago by managing the maintenance of its own internal inventory of over 2,000 tools across 18 sites worldwide. This experience provided a unique and invaluable understanding of the challenges involved, particularly the impact of unexpected parts unavailability. The solutions and robust processes developed to serve its own needs are now leveraged to benefit Testia's external customers, providing them with a level of experience and reliability that is simply not available from providers who lack such a foundational history.

The tangible results of this integrated approach are validated by key industry partners. According to Laurent Place, Contract Execution Pilot from the DMAé (the Maintenance Department of the French Airforce), "Testia's expertise and our partnership have demonstrated their ability to achieve the expected operational performance objectives" according to their specifications. This underscores Testia's ability to translate strategic service delivery into real-world operational success for the most rigorous clients.

Enabling uninterrupted operations

The future of industrial testing is defined by the twin demands of safety and efficiency in the face of profound systemic pressures. Testia's MOC service represents a strategic evolution in how the industry manages its most critical assets. By transforming the complex, non-core activity of equipment maintenance into a core excellence, Testia enables its customers to streamline their operations, reduce risk, and focus on their primary mission. Supported by a fixed-price structure for financial predictability, Testia's end-to-end approach guarantees tool availability, minimizes costly downtime, and ensures that the ultimate goal of structural safety is always a reality.



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Structural integrity is your priority, securing your tools is ours.

Introducing the new Maintenance in Operational Condition (MOC) service from Testia, an end-to-end solution ensuring the readiness of your inspection equipment. We manage every step of your equipment lifecycle, from sourcing and maintenance to periodic verification and obsolescence management.

We provide the compliant tools, you provide the expert inspections.

TESTIA:
YOUR PARTNER IN SECURING
INSPECTION EQUIPMENT READINESS



Ready to streamline
your NDT workflow?

A Conversation with Dr. Kishore Brahma: On Fatigue, Failure, and Flight Safety



Consultant

umlaut company (A part of Accenture)

Q: Dr. Kishore Brahma, welcome to OnestopNDT—it is a pleasure to have you with us. With more than three decades of experience spanning aerospace research, industry leadership, consulting, and academia, could you share how your journey in structural integrity and Fatigue & Damage Tolerance (F&DT) evolved over the years?

A: I extend my greetings to everyone and express my gratitude to OnestopNDT for the privilege of sharing my journey with you. My journey in structural integrity and Fatigue & Damage Tolerance has really been a story of evolution across different phases of my career. I began in aerospace research, where my focus was on understanding the fundamentals of fatigue and crack growth. My early years taught me experimental methods and the importance of being accurate and careful.

As I moved into industry leadership roles, the emphasis shifted from theory to application. Working on major aerospace programs, I had to balance safety, performance, and cost. It was here that I learned how F&DT principles translate into real-world design decisions, certification processes, and fleet sustainment.



With over three decades of experience across aerospace research, industry leadership, consulting, and academia, Dr. Kishore Brahma has made significant contributions to structural integrity and Fatigue & Damage Tolerance (F&DT). In this interview with OnestopNDT, he shares insights from his journey, highlighting the evolution of fatigue analysis, the role of inspection techniques, and the growing importance of digital tools and collaboration in ensuring aircraft safety and airworthiness.

Later, in consulting, I had the privilege of advising organizations across commercial aviation. It allowed me to contribute to best practices and standards that had an impact beyond a single company.

My academic phase has been equally rewarding. Teaching and mentoring young engineers gave me the chance to pass on lessons learned from both research and industry.

Over the decades, I have witnessed the discipline itself evolve. When I started, fatigue analysis was largely empirical and deterministic. Today, we are integrating AI, big data, and predictive analytics into damage tolerance frameworks.

If I had to summarize, my journey has been about connecting the dots—linking fundamental science, practical engineering, policy, and education. Structural integrity and F&DT are ultimately about safeguarding lives while enabling innovation, and that has been the guiding principle throughout my career.

Q: You began your career in research at the National Aerospace Laboratories after completing your Ph.D. from the Indian Institute of Science. How did your early research experience shape your approach to aircraft structural integrity and life prediction?

A: My early research at the Indian Institute of Science and later at the National Aerospace Laboratories was pivotal in shaping my approach to aircraft structural integrity and life prediction. At IISc, my doctoral work on fatigue crack propagation gave me a strong grounding in the fundamentals of crack growth behaviour. At NAL, I had the opportunity to apply these principles to real-world aerospace challenges—conducting full-scale fatigue tests on fighter aircraft, evaluating helicopter components, and characterizing advanced materials such as aluminium-lithium alloys under corrosive environments.

These experiences taught me

that structural integrity is not just about theoretical models, but about integrating experimental data, operational loads, and environmental effects into a holistic understanding of aircraft life. Working on life evaluation and extension programs for both fixed-wing aircraft and helicopters reinforced the importance of linking laboratory research with fleet sustainment. This foundation has guided me throughout my career—whether in industry, consulting, or academia—ensuring that my approach to F&DT always balances scientific rigor with practical application.

Q: You began your career in research at the National Aerospace Laboratories after completing your Ph.D. from the Indian Institute of Science. How did your early research experience shape your approach to aircraft structural integrity and life prediction?

A: Early in my career, I was involved in non-destructive evaluation using



acoustic emission monitoring at the Indian Institute of Science and later at the National Aerospace Laboratories. These studies were crucial because they provided real-time insights into crack initiation and growth, enabling us to detect damage before it became critical. Acoustic emission techniques, along with other inspection methods, allowed us to validate fatigue life predictions and strengthen confidence in structural integrity assessments.

Working on aircraft components and full-scale fatigue tests, I realized that inspection techniques are not just supplementary—they are integral to linking analytical models with operational reality. They help bridge the gap between theoretical crack growth predictions and the actual behaviour of materials under service loads and environments. This early exposure instilled in me the conviction that robust inspection and monitoring are essential pillars of damage tolerance philosophy, and that conviction has guided my approach throughout my career in research, industry, consulting, and academia.

Q: Fatigue and Damage Tolerance analysis is central to aircraft certification. For readers who may be less familiar with this domain, could you explain why F&DT methodologies are critical for ensuring long-term aircraft safety and airworthiness?

A: Fatigue and Damage Tolerance (F&DT) analysis is fundamental to aircraft certification because it directly addresses how structures behave under repeated loading over their entire service life. Aircraft are subjected to millions of cycles of stress—from take-offs, landings, pressurization, and environmental effects—and even small cracks can grow over time if not properly understood and managed. F&DT methodologies provide the framework to predict crack initiation and growth, establish inspection

intervals, and define allowable damage limits.

In practice, this ensures that aircraft can continue operating safely even with minor defects, as long as they are within certified limits and monitored appropriately. It also underpins life extension programs, repair strategies, and compliance with international regulations such as FAR and CS standards. Without robust F&DT analysis, long-term airworthiness would be compromised, as there would be no scientific basis to balance safety with operational efficiency. In essence, F&DT is the discipline that allows us to anticipate, detect, and control structural degradation—safeguarding lives while enabling aircraft to remain in service reliably for decades.

Q: You have contributed to several aircraft programs and certification activities aligned with global standards such as FAR and CS regulations. What are some of the most complex challenges engineers face when performing fatigue life prediction and damage tolerance analysis?

A: Fatigue life prediction and damage tolerance analysis

are among the most complex tasks in aircraft certification because they require engineers to account for multiple uncertainties simultaneously. One major challenge is the variability in operational load spectra—aircraft experience millions of cycles under diverse conditions, and accurately representing these loads is critical. Material behaviour adds another layer of complexity, as crack initiation and growth can be influenced by microstructural variations, manufacturing processes, and environmental factors such as corrosion.

Another challenge lies in balancing analytical predictions with experimental validation. While advanced tools like NASGRO, AFGROW, and DARWIN provide powerful modelling capabilities, engineers must still reconcile these results with full-scale fatigue tests and inspection data. Developing repair methodologies and life extension strategies for in-service fleets also demands careful consideration, since even minor deviations can affect safety margins.

Finally, compliance with global standards such as FAR and CS regulations requires rigorous documentation, justification, and

alignment with certification authorities. The complexity is not only technical but also procedural—ensuring that every analysis, repair, and inspection plan meets regulatory expectations while remaining practical for operators. These challenges make F&DT a discipline where scientific rigor, engineering judgment, and regulatory knowledge must come together seamlessly to ensure long-term airworthiness.

Q: Over the years, computational tools like NASGRO, AFGROW, DAMTOL, and DARWIN have become integral to fracture mechanics and structural life assessment. How have such tools transformed engineering analysis compared to earlier methodologies?

A: When I began my career, fatigue and damage tolerance assessments relied heavily on empirical methods, manual calculations, and extensive chart-based evaluations. While these approaches provided valuable insights, they were often time-consuming and limited in their ability to capture the complexity of crack growth under variable loading conditions.

The advent of computational tools such as NASGRO, AFGROW, DAMTOL, and DARWIN has transformed this landscape. These tools allow engineers to model crack initiation and growth with far greater accuracy, incorporate probabilistic methods, and simulate diverse load spectra efficiently. They also enable sensitivity studies, life prediction under spectrum loading, and integration of inspection intervals—all of which are critical for certification and fleet sustainment.

In practice, this means engineers can now move from conservative, generalized estimates to data-driven, scenario-specific predictions. The result is not only improved safety margins but also optimized maintenance schedules and extended service life for aircraft. For me, having worked across

research, industry, and consulting, these tools have been instrumental in bridging theoretical fracture mechanics with practical, regulatory-compliant solutions.

Q: Your career includes leadership roles in organizations such as AXISCADES Engineering Technologies Ltd., Tech Mahindra, and Cyient, where you built and led F&DT teams. How important is competency development when working in highly specialized engineering domains?

A: Competency development is vital in specialized domains like Fatigue & Damage Tolerance. When I led F&DT teams at Cyient, Tech Mahindra, and AXISCADES, one of my priorities was not just delivering technical solutions but building organizational capability. The complexity of fatigue life prediction and damage tolerance analysis requires engineers to master tools, understand regulatory frameworks such as FAR and CS standards, and apply lessons from past accidents to ensure continued airworthiness.

As highlighted in industry practice, F&DT is not a core subject at the graduate level, which means many engineers enter the workforce without deep domain knowledge. Bridging this gap through structured training, mentoring, and industry-centric courses becomes essential. In my leadership roles, I invested in preparing guidelines, developing methodologies, and mentoring engineers so that teams could consistently deliver high-quality analyses and certification support.

Ultimately, competency development transforms individual skill into collective strength. It ensures that organizations can meet the growing demand for F&DT expertise—whether in design, repair justification, or life extension—and sustain long-term safety and airworthiness. For me, nurturing this competency has been one of the most impactful aspects of my career.

Q: In your current consulting role with Umlaut, you are supporting fatigue and damage tolerance certification activities for commuter aircraft. How does consulting for certification programs differ from working within large engineering organizations?

A: Consulting for certification programs differs significantly from working within large engineering organizations. In a corporate setting, F&DT activities are often distributed across specialized teams, with established processes, infrastructure, and long-term program support. As a consultant, however, the role is more focused, independent, and outcome-driven. I am directly responsible for preparing methodologies, guidelines, and justifications that meet regulatory requirements, while also providing technical guidance to client teams. This means interpreting standards such as FAR and CS regulations and ensuring that every analysis aligns with airworthiness expectations.

The difference lies in accountability and scope: in consulting, one's contribution is highly visible and directly tied to certification milestones. It demands not only technical depth but also clarity in communication, adaptability to diverse client needs, and the ability to bridge gaps between design, analysis, and regulatory compliance.

Q: Beyond technical leadership, you have played a key role in developing aerospace training programs and Centres of Excellence. What gaps do you see today between academic curricula and the practical skills required in the aerospace industry?

A: In my experience, there remains a significant gap between academic curricula and the practical skills required in the aerospace industry. At the



graduate level, subjects like fatigue and fracture mechanics are often taught as electives, which means many students graduate without deep exposure to Fatigue & Damage Tolerance (F&DT). Yet, F&DT is central to certification, repair justification, and life extension of aircraft, and its importance has only grown since regulatory mandates such as FAR-25.571 and FAR-121.370a.

When I led training programs and Centres of Excellence, I saw that bridging this gap requires more than classroom theory. Students and young engineers need industry-centric content and an understanding of regulatory frameworks and repair methodologies. Without this, they struggle to connect analytical models with operational realities.

Competency development through structured training, mentoring, and collaboration with subject matter experts is therefore essential. It not only equips engineers to meet certification demands but also ensures organizations have the skilled workforce needed to sustain long-term airworthiness. Closing this gap between academia and industry practice has been one of my key priorities throughout my career.

Q: You have been involved with national expert committees and initiatives related to aircraft life extension and structural integrity. How important is collaboration between research institutions, industry, and government bodies in strengthening the aerospace ecosystem?

A: Collaboration between research institutions, industry, and government bodies is essential for strengthening the aerospace ecosystem. Each brings a unique perspective—research institutions provide scientific rigor and innovation, industry ensures practical application



and scalability, while government bodies establish regulatory frameworks and long-term national priorities. My involvement in national expert committees for aircraft and engine life extension, as well as initiatives like the Main Airframe Fatigue Test of a fighter aircraft, has shown how powerful this synergy can be.

For example, life extension programs for military aircraft and helicopters require integrating laboratory data, fleet usage patterns, and regulatory oversight. No single stakeholder could have achieved this alone. By working together, we are able to evolve guidelines, validate methodologies, and ensure continued airworthiness while optimizing resources.

Such collaboration not only addresses immediate certification and sustainment needs but also builds a resilient ecosystem—one that nurtures competency development, advances structural integrity practices, and safeguards lives while enabling innovation. It is this collective effort that

ensures aerospace programs remain robust and future-ready.

Q: On a personal note, after decades of working on highly technical aerospace challenges, how do you like to spend your time outside of work? Are there hobbies or interests that help you relax and stay inspired?

A: Outside of my professional work, I engage in activities that help me unwind and stay inspired. I enjoy listening to classic songs from the 1970s to 1990s, regularly sharing technical insights on LinkedIn, and continuously enriching my training materials with relevant updates and videos. Exploring technical literature as well as broader subjects keeps my mind active and often provides fresh perspectives. I also find great satisfaction in mentoring young engineers and students informally—it is both relaxing and rewarding to share experiences in a less structured setting.

I contribute actively to professional

bodies such as the Indian Structural Integrity Society (InSIS) and the Aeronautical Society of India, Bangalore Branch (AeSIBB). This includes delivering webinars and invited talks to aeronautical students across various colleges, with the aim of disseminating the importance of fatigue and damage tolerance (F&DT) and structural integrity in aircraft design. To stay abreast of advancing technologies, I attend sessions and courses whenever possible. In addition, I regularly explore and practice with different AI tools, integrating them into my professional activities to enhance productivity & innovation.

Q: With the increasing use of advanced materials, digital engineering, and predictive maintenance, how do you see fatigue analysis and structural life management evolving in the aerospace sector over the next decade?

A: Over the next decade, fatigue analysis and structural life management will evolve significantly with the increasing use of advanced materials, digital engineering, and predictive maintenance. Traditionally, F&DT relied on empirical methods and deterministic models, but the introduction of composites, hybrid materials, and additive manufacturing demands new approaches to crack initiation and growth prediction. These materials behave differently under cyclic loading, requiring more sophisticated characterization and modelling.

Digital engineering is transforming how we approach structural integrity. With digital twins, engineers can simulate aircraft behaviour under real operating conditions, continuously updating models with in-service data. This enables predictive maintenance—moving from scheduled inspections to condition-based monitoring—where potential issues are identified before

they become critical. Tools like NASGRO, AFGROW, and DARWIN are already integrating probabilistic methods, and in the future, they will be coupled with big data analytics and AI to provide real-time life assessments.

The result will be a more proactive and precise approach to airworthiness. Instead of relying solely on conservative margins, we will have dynamic, data-driven insights that extend service life, optimize maintenance, and enhance safety. For me, this evolution reflects the same principle that has guided my career: combining scientific rigor with practical application to safeguard lives while enabling innovation.

Q: Having mentored engineers, guided academic projects, and delivered training programs globally, what advice would you give to young engineers aspiring to specialize in structural integrity and advanced engineering analysis?

A: My advice to young engineers aspiring to specialize in structural integrity and advanced engineering analysis is to build a strong foundation in fundamentals while staying open to continuous learning. Fatigue and Damage Tolerance is not always taught as a core subject, so it is important to actively seek knowledge through electives, specialized courses, and guidance from subject matter experts. Tools like NASGRO, AFGROW, and DARWIN are powerful, but they are only effective when combined with a deep understanding of fracture mechanics, materials behaviour, and regulatory frameworks.

Mentorship and collaboration also play a vital role; learning from experienced professionals accelerates growth and helps bridge the gap between academic knowledge and industry requirements.

Finally, cultivate curiosity and resilience. Structural integrity is a discipline that evolves with new

materials, digital engineering, and predictive maintenance. Staying inspired by innovation while grounded in fundamentals will prepare you to contribute meaningfully to the aerospace sector and safeguard lives through your work.

Q: Finally, platforms like OnestopNDT aim to connect researchers, engineers, inspection professionals, and technology providers. From your perspective, how valuable are such platforms in fostering knowledge exchange and advancing engineering disciplines related to inspection, testing, and structural integrity?

Platforms like OnestopNDT are **A:** invaluable in advancing disciplines such as inspection, testing, and structural integrity. By connecting researchers, engineers, inspection professionals, and technology providers, they create a collaborative ecosystem where knowledge flows seamlessly between academia, industry, and regulatory practice.

This exchange not only accelerates competency development but also ensures that lessons learned across programs are shared globally. In a field where safety and innovation must coexist, such platforms play a vital role in strengthening the aerospace community and inspiring the next generation of engineers.

This conversation with Dr. Kishore Brahma highlights the critical role of Fatigue & Damage Tolerance in ensuring aircraft safety and reliability. From foundational research to advanced digital tools and predictive analytics, his insights underscore the importance of integrating theory, experimentation, and real-world application. As aerospace engineering continues to evolve, the emphasis on competency development, collaboration, and innovation will remain key to sustaining structural integrity and advancing the future of aviation.



Insights

Pipeline Inspection in Oil and Gas Terminals

Understanding corrosion threats and inspection techniques in pipeline systems.



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Pipelines form the backbone of fluid transfer systems in oil and gas terminals. They connect storage tanks, pumping stations, marine loading arms, truck and rail loading racks, and processing units. Through these interconnected networks, large volumes of hydrocarbons are transported continuously under controlled pressure and flow conditions. Because these pipelines handle flammable, hazardous, and often high-value products, maintaining their integrity is essential for safe, environmentally responsible, and efficient terminal operations.

Pipeline failures in terminal environments can have severe consequences, including fire or explosion hazards, environmental contamination, product loss, operational disruptions, and reputational damage. For this reason, systematic pipeline inspection and integrity management programs are fundamental elements of terminal operation and maintenance practices. A well-designed inspection strategy allows operators to identify degradation mechanisms at an early stage and take preventive measures before failures occur.

Because of these complexities, pipelines within terminals require a structured inspection and monitoring program to ensure long-term reliability.

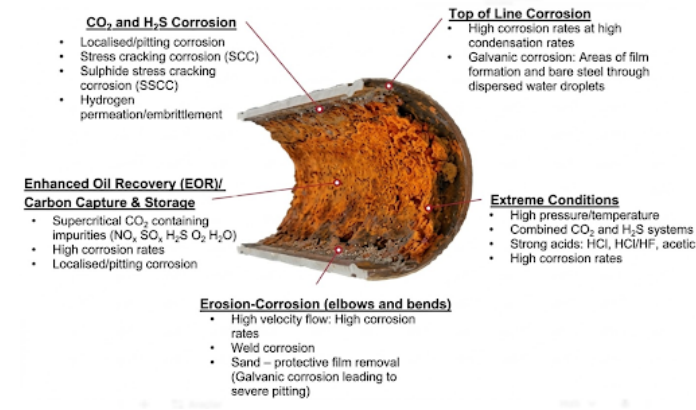
1. Common Degradation Mechanisms in Terminal Pipelines

Understanding the typical failure mechanisms affecting pipelines is essential for designing an effective inspection program.

1.1.Internal Corrosion

Internal corrosion occurs when chemical or electrochemical reactions between the pipeline material and the transported fluid gradually degrade the internal pipe wall, leading to metal loss and potential integrity issues. In hydrocarbon pipelines, this type of corrosion is often driven by water contamination within the hydrocarbon stream, which can create localized electrochemical cells that accelerate metal dissolution. Dissolved gases such as hydrogen sulfide (H₂S) and carbon dioxide (CO₂) can further exacerbate corrosion by forming acidic solutions in contact with the

metal surface. Microbiologically influenced corrosion (MIC), caused by the activity of certain bacteria that produce corrosive byproducts, can lead to highly localized pitting and material loss.



Additionally, acidic or sulfur-containing compounds naturally present in crude oil may attack the pipe material over time, gradually thinning the wall and reducing structural integrity. If left undetected, internal corrosion can result in leaks, ruptures, and operational downtime, making routine monitoring and mitigation strategies such as corrosion-resistant materials, and internal coatings essential for safe pipeline operation.

1.2.External Corrosion

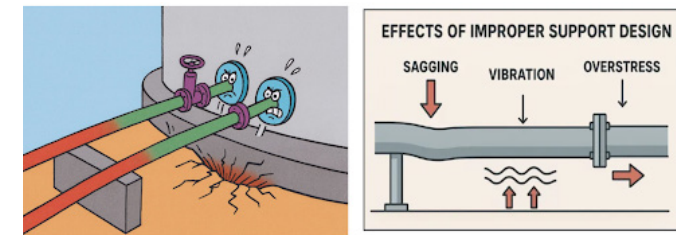
External corrosion develops on the outer surface of pipelines and is primarily driven by environmental exposure and the degradation of protective barriers. The most immediate contributing factor is damage or deterioration of protective coatings, which normally shield the metal from direct contact with moisture and oxygen.

When coatings are compromised, water, oxygen, and other corrosive agents in the environment can interact with the pipe surface, initiating and accelerating the corrosion process. In buried pipelines, soil conditions such as acidity, moisture content, and chemical composition play a critical role in the rate and severity of corrosion. Stray electrical currents from nearby electrical systems can also induce corrosion through electrochemical reactions on the pipeline surface. Additionally, ineffective or improperly maintained cathodic protection systems which are designed to counteract corrosion by providing a controlled electrical current can leave sections of the pipeline vulnerable. Over time, these factors can result in significant material loss, weakening the structural integrity of the pipeline and increasing the risk of leaks or failures if not detected and mitigated through regular inspection and maintenance.



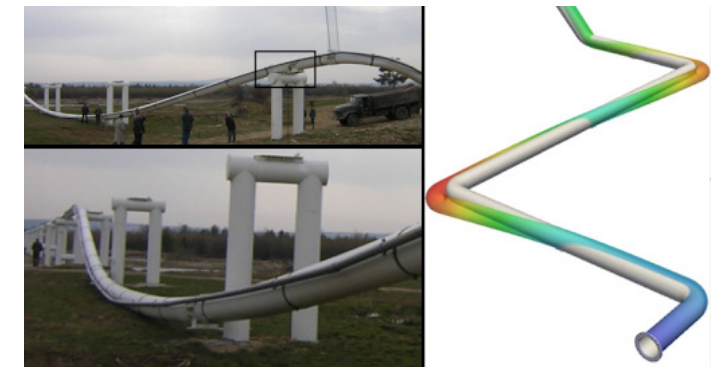
1.3.Mechanical Damage

Mechanical damage in pipelines can arise from a variety of operational and external factors that introduce abnormal stresses or physical impact on the system. One of the most common causes is impact from vehicles or mobile equipment operating near the pipeline, particularly in industrial facilities where forklifts, trucks, or heavy machinery frequently move through pipe rack areas.



Damage may also result from improper pipe supports or misalignment, which can create uneven load distribution and lead to localized stresses over time. Thermal expansion and contraction during normal operating cycles can generate significant stresses if expansion allowances are insufficient or if the pipeline is improperly constrained. In addition, vibrations generated by pumps, compressors, or other rotating equipment can gradually weaken pipe connections, supports, and welds when not properly isolated or dampened. Mechanical damage can also occur during maintenance activities, especially when work is carried out without adequate protection of nearby piping systems or when improper tools and handling practices are used. Over time, these factors may lead to deformation, cracks, or structural weakening of the pipeline, potentially

compromising the integrity and safe operation of the system.



1.4.Erosion

Erosion is a form of mechanical wear caused by the high-velocity flow of fluids carrying solid particles, liquid droplets, or other entrained materials that repeatedly impact the internal surface of a pipeline. Over time, these impacts remove small amounts of material from the pipe wall, gradually thinning the metal and potentially leading to loss of containment if not detected in time.

In terminal pipelines, erosion is most commonly observed in areas where the flow velocity increases or where turbulence is generated. Typical locations include pump discharge lines, pipe bends, reducers, tees, and control valves. In these sections, changes in flow direction or cross-section create localized turbulence and accelerate the fluid stream, increasing the intensity of particle impingement on the pipe wall.

The severity of erosion depends on several factors, including fluid velocity, particle size and concentration, material hardness, and flow regime. Even relatively small particles can cause significant damage when transported at high velocity over extended operating periods. In multiphase systems, such as lines carrying liquid and vapor phases, droplets can also contribute to erosive wear.

To mitigate erosion risks, proper pipeline design, controlled flow velocities, material selection, and periodic inspection methods such as ultrasonic thickness measurements are essential. Early identification of erosion-prone locations allows operators to implement preventive maintenance strategies before significant wall loss occurs.

2. Pipeline Inspection Techniques

A comprehensive pipeline inspection program typically combines several non-destructive examination (NDE) methods to detect different types of defects.

2.1. Visual Inspection

Visual inspection is one of the most fundamental yet essential inspection techniques used in pipeline integrity management. It involves the systematic examination of pipelines and associated components in order to identify visible signs of damage, deterioration, External corrosion or abnormal operating conditions. During these inspections, particular attention is given to external corrosion that may develop on the pipe surface due to environmental exposure, as well as damage or degradation of protective coatings that normally serve as the first barrier against corrosion. Inspectors also evaluate the adequacy and condition of pipe supports, since poor or misaligned supports can lead to excessive stress and long-term structural problems.

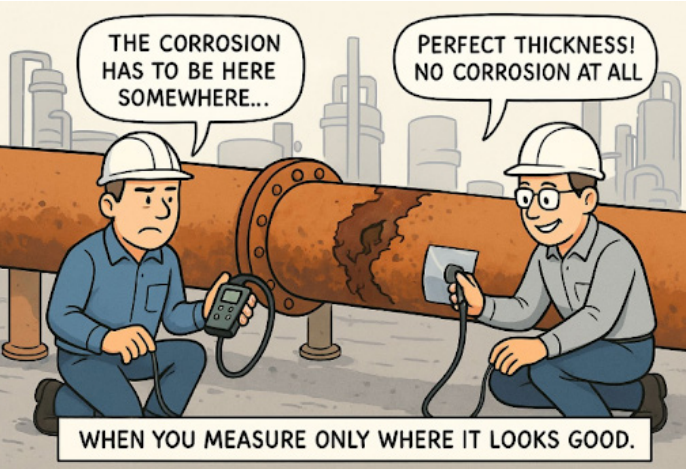


In addition, the pipeline is checked for any form of deformation such as dents or bending that could indicate mechanical stress or external loading. The integrity of flanges and the condition of gaskets are also carefully

assessed because leakage or misalignment in these components may compromise system tightness. Finally, inspectors look for evidence of mechanical impact or external interference, such as marks caused by vehicles, tools, or nearby construction activities. Although visual inspection is a relatively simple and low-cost method, when carried out regularly and systematically it can provide valuable early warning signs of integrity issues, allowing corrective actions to be implemented before minor defects evolve into serious operational or safety risks.

2.2. Ultrasonic Thickness Measurement (UT)

Ultrasonic testing is one of the most widely used techniques for monitoring corrosion in pipelines. Using ultrasonic waves, inspectors can measure the remaining wall thickness of pipes without removing them from service.



Thickness measurements are typically taken at predefined corrosion monitoring locations (CMLs). By repeating measurements periodically, engineers can calculate corrosion rates and estimate the remaining service life of the pipeline.

2.3. Radiographic Testing (RT)

Radiographic Testing (RT) is a non-destructive examination technique that uses X-rays or gamma rays to evaluate the internal structure of pipeline welds and pipe sections without damaging the material. The method works by passing radiation through the component and capturing the transmitted rays on a detector or radiographic film, producing an image that reveals variations in material density. These variations allow inspectors to identify internal defects that cannot be detected through visual inspection alone.

Radiographic testing is particularly effective in detecting weld-related imperfections such as lack of fusion between weld metal and base material, internal porosity formed by trapped gases during welding, cracks that may develop due

to thermal stresses or material defects, and slag inclusions resulting from improper welding practices. Because of its ability to provide a clear representation of internal weld quality, radiography is widely used during pipeline construction, fabrication, and major repair activities to verify that welds meet required quality and safety standards before the pipeline is placed into service.



2.4. Magnetic Particle Inspection (MPI)

Magnetic particle inspection is used to detect surface and near-surface cracks in ferromagnetic materials. It is frequently applied to welded joints, flanges, and fittings where stress concentrations occur.

2.5. Dye Penetrant Testing (PT)

Dye penetrant testing is another method used to detect surface-breaking cracks. A liquid penetrant is applied to the surface and allowed to seep into cracks, which are then revealed using a developer.

This method is often used in combination with other inspection techniques during maintenance shutdowns.

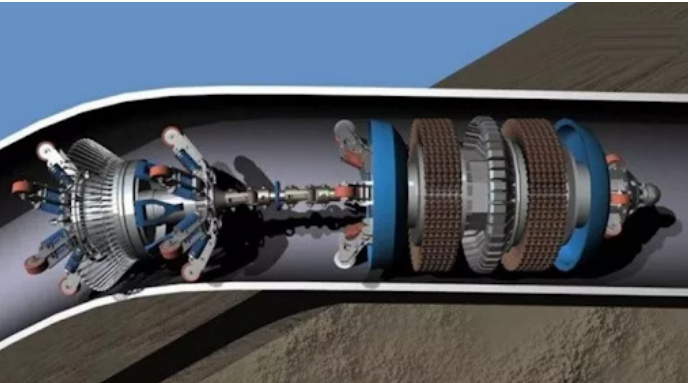


2.6. In-Line Inspection (Intelligent Pigging)

In-line inspection (ILI), commonly referred to as intelligent pigging, is an advanced non-destructive inspection

technique used to assess the internal condition of pipelines while they remain in operation. In this method, specialized inspection tools known as intelligent pigs travel through the pipeline, propelled by the product flow, and collect detailed data on the pipe's structural integrity. These tools are equipped with sophisticated sensors capable of identifying a wide range of defects, including corrosion, metal loss, cracks, dents, and geometric deformations that may affect pipeline performance and safety.

Several technologies are commonly employed in intelligent pigging systems, such as Magnetic Flux Leakage (MFL) for detecting metal loss and corrosion, ultrasonic inspection for accurately measuring wall thickness and identifying internal defects, and caliper tools that measure pipeline geometry to detect dents, ovalization, or other dimensional changes. Although pipelines within storage terminals are often shorter and contain more bends, valves, and complex routing compared to long-distance transmission pipelines, intelligent pigging can still be effectively applied in certain transfer lines or straight sections where pipeline geometry and operational conditions permit the passage of inspection tools.

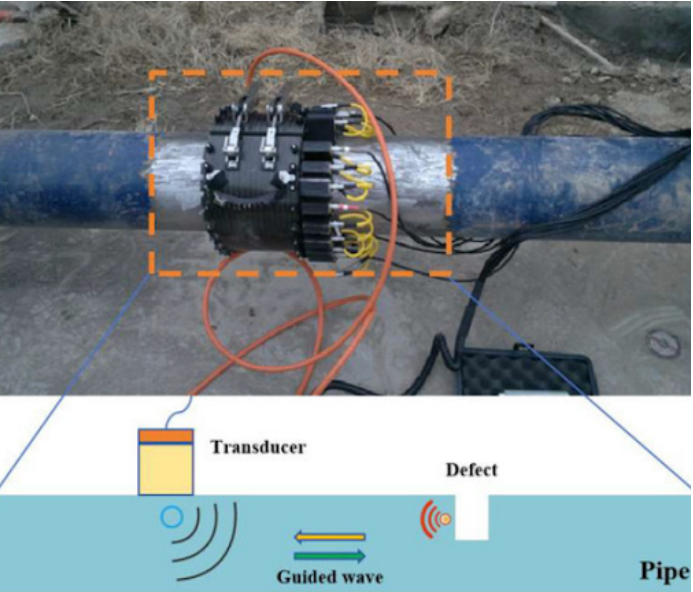


2.7. Guided Wave Testing (GWT)

Guided Wave Testing (GWT) is a non-destructive inspection technique used to evaluate the condition of pipelines over relatively long distances from a single test location. The method works by introducing low-frequency ultrasonic waves into the pipe wall using specialized transducers mounted around the circumference of the pipe. These waves travel along the length of the pipeline and reflect back when they encounter changes in geometry or material condition, such as corrosion, wall thinning, cracks, or other structural anomalies. By analyzing the reflected signals, inspectors can identify and estimate the location of potential defects without the need to access the entire pipeline surface.

Guided wave testing is particularly useful for inspecting pipelines in areas that are difficult to access, such as sections buried underground, pipes passing through walls, or pipelines located under insulation or supports. In terminal

facilities, this technique is often applied as a screening tool to quickly assess long pipe segments and identify areas that may require more detailed inspection using other non-destructive testing methods. While guided wave testing does not typically provide the same level of precise defect sizing as some other techniques, it offers significant advantages in terms of speed, coverage distance, and reduced need for extensive excavation or insulation removal.



3. Corrosion Monitoring and Prevention

Because corrosion is one of the most significant threats to pipeline integrity, effective corrosion control programs are essential. Corrosion gradually reduces pipe wall thickness and may eventually lead to leaks, ruptures, and serious safety or environmental incidents if it is not properly monitored and controlled. To effectively manage corrosion, operators implement corrosion monitoring programs that combine several techniques. These may include periodic ultrasonic thickness measurements, corrosion coupons, electrical resistance probes, and smart pigging inspections where applicable. Regular monitoring allows engineers to track corrosion rates and identify areas where wall loss is occurring before the integrity of the pipeline is compromised. Preventive measures are equally important. Proper material selection, protective coatings, and cathodic protection systems are widely used to prevent external corrosion. For internal corrosion control, operators may apply corrosion inhibitors, remove water from the system, or improve filtration to reduce contaminants. Maintaining proper operating conditions and performing routine

inspections are also key elements of a comprehensive corrosion management strategy.



3.1. Protective Coatings

Protective coatings act as a barrier between the metal surface and the environment. Properly applied coatings significantly reduce the rate of external corrosion. However, coatings may degrade over time due to environmental exposure, mechanical damage, or improper application. Regular inspection is therefore necessary to identify coating defects.

3.2. Cathodic Protection

Cathodic protection is a critical method for preventing corrosion on pipelines by applying a controlled electrical current that counteracts the natural electrochemical reactions responsible for metal degradation. This technique effectively shifts the pipeline to a cathodic state, reducing or halting the corrosion process. Two primary types of cathodic protection systems are commonly employed: sacrificial anode systems, which use more reactive metals to corrode in place of the pipeline, and impressed current systems, which rely on an external power source to provide a continuous protective current. Cathodic protection is especially vital for buried pipelines and those exposed to highly corrosive environments, such as soils with high moisture or aggressive chemical content, where the risk of external corrosion is significant.



4. Risk-Based Inspection (RBI)

Risk-Based Inspection (RBI) represents a modern approach to pipeline integrity management, moving beyond traditional fixed-interval inspection programs by prioritizing inspections based on risk. RBI involves evaluating both the probability of failure and the potential consequences for each pipeline segment, allowing inspection and maintenance efforts to focus on areas that pose the highest risk to safety, the environment, and operational continuity. Key factors considered in an RBI assessment include operating conditions such as pressure and temperature, the type of product being transported, historical corrosion or damage data, pipeline age, environmental sensitivity, proximity to populated or critical areas, and the operational importance of the pipeline segment. By integrating these factors, RBI enables terminal operators to optimize inspection intervals, allocate resources more efficiently, and proactively address potential integrity issues before they result in failures. This data-driven approach enhances safety, reduces unplanned downtime, and supports cost-effective maintenance planning.

5. Conclusion

Pipeline inspection is a critical element of safe and reliable operations in oil and gas terminals. Because pipelines transport large volumes of flammable hydrocarbons under pressure, even minor defects can lead to significant safety and environmental risks if left undetected. A comprehensive pipeline integrity program should include regular visual inspections, non-destructive testing techniques, corrosion monitoring, and risk-based inspection methodologies. Combining these approaches allows terminal operators to detect early signs of degradation and implement timely maintenance actions. In modern oil and gas terminals, digital inspection management systems and advanced diagnostic tools are further enhancing the ability of engineers to monitor pipeline condition and predict potential failures. Through systematic inspection and proactive integrity management, operators can extend pipeline service life, protect personnel and the environment, and ensure the uninterrupted transfer of hydrocarbon products.



Managing Internal Corrosion Risk in Carbon Steel Pipelines Under Intermittent Seawater Exposure: Inspection and Integrity Perspectives.



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The Anti Corrosion Experts FZ LLC Dubai

Pipeline integrity management remains a critical priority in the oil and gas industry, where corrosion continues to be one of the primary causes of pipeline degradation and operational risk. While significant effort is often placed on controlling external corrosion through protective coatings, cathodic protection, and inspection programs, internal corrosion can develop unnoticed and progress rapidly under unfavorable operating conditions. Carbon steel pipelines are widely used in industrial facilities for transporting fresh water, cooling water, and other utility fluids due to their strength, availability, and cost efficiency. Under stable fresh water conditions, internal corrosion of carbon steel typically occurs at relatively low rates and is largely influenced by dissolved

oxygen levels, water chemistry, and hydraulic conditions. However, even temporary changes in the operating environment can significantly alter corrosion behavior. One such situation arises when seawater inadvertently enters a pipeline designed for fresh water service. The presence of chlorides, increased electrolyte conductivity, and marine microorganisms can destabilize corrosion product films and promote localized corrosion mechanisms. Even short periods of saline exposure may initiate corrosion processes that continue to develop long after the original disturbance has passed. This article presents a practical pipeline integrity case involving severe internal corrosion observed in a carbon steel pipeline originally designed for fresh water distribution. The investigation highlights the role of intermittent seawater intrusion in accelerating internal corrosion and discusses how inspection and non-destructive testing (NDT) methods support corrosion detection and integrity management.

Pipeline System Description

The pipeline investigated in this case formed part of a fresh water distribution system on a 16-year-old oil tanker vessel undergoing dry-dock maintenance. The system consisted of carbon steel piping designed to transport fresh water produced onboard through generation systems such as evaporators or reverse osmosis units. Under normal operating conditions, the pipeline carried low-salinity water with moderate dissolved oxygen levels. The internal surface of the pipe was uncoated, which is a common design practice for fresh water systems where the corrosion risk is generally considered manageable. Operational records later indicated that during periods when the fresh water generation system experienced breakdowns, the pipeline was temporarily supplied with seawater through a bypass arrangement in order to maintain essential services. Although these periods were relatively short, they introduced seawater into a pipeline that had not been designed for saline service. Seawater contains significantly higher concentrations of dissolved salts, particularly chloride ions, along with increased electrical conductivity and marine biological activity. Even intermittent exposure to such conditions can alter the corrosion environment within carbon steel pipelines. Repeated exposure cycles may prevent the formation of stable corrosion product films and create conditions that promote localized corrosion processes.

Observed Corrosion Damage

During scheduled maintenance activities, a section of the pipeline was removed for inspection. Visual examination of the internal pipe surface revealed extensive corrosion product buildup and significant obstruction of the flow path. Large nodular corrosion deposits, commonly referred to as tubercles, were observed projecting inward from the internal pipe wall. These deposits consisted mainly of iron oxide corrosion products formed as a result of electrochemical reactions between the steel surface and the surrounding electrolyte.



Figure -1 Internal corrosion deposits in the carbon steel pipeline showing extensive tuberculation and significant reduction in the effective internal diameter.



Figure -2 Localized corrosion near a flange connection where flow disturbance and deposit accumulation create conditions favorable for differential aeration corrosion.

The corrosion deposits exhibited a layered structure with porous outer oxide layers and darker internal regions. Such morphology is typical of oxygen-driven corrosion processes that occur beneath stabilized corrosion products. Corrosion was not uniformly distributed throughout the pipe. Instead, degradation was concentrated in localized regions, particularly near flange connections and areas where flow disturbances are likely to occur. These regions often create conditions that favor sediment accumulation and reduced fluid velocity.

After partial removal of corrosion deposits, significant under-deposit pitting corrosion was observed beneath the tubercles. The pits displayed irregular cavity shapes and localized penetration relative to surrounding surfaces. This type of localized attack is particularly critical because metal loss may progress rapidly in small areas while the surrounding pipe wall remains relatively intact.



Figure -3 Cross-section of the removed pipeline section illustrating severe internal obstruction caused by corrosion product buildup and localized metal loss beneath deposits.

Corrosion Mechanisms

The internal corrosion observed in this pipeline resulted from the combined influence of chemical, electrochemical, and hydraulic factors associated with intermittent seawater exposure.

Chloride-Induced Corrosion

Seawater contains high concentrations of chloride ions that significantly influence corrosion behavior in carbon steel systems. Chlorides are known to penetrate and destabilize protective corrosion product films that may form on the steel surface under fresh water conditions.

When these films break down, localized anodic regions develop where metal dissolution occurs. The repeated introduction of seawater followed by

fresh water operation prevented the formation of stable corrosion layers and sustained localized electrochemical activity within the pipeline.

Differential Aeration

Accumulated corrosion deposits created localized areas beneath the tubercles where oxygen diffusion was limited compared to surrounding surfaces. This oxygen concentration difference resulted in the formation of differential aeration cells. Within these cells, regions with reduced oxygen concentration acted as anodic sites where metal dissolution occurred, while adjacent oxygen-rich regions functioned as cathodic surfaces. The resulting electrochemical potential difference drove localized corrosion beneath the deposits.

Under-Deposit Corrosion

The porous structure of corrosion products allowed retention of electrolyte beneath the deposits. These occluded regions often contained concentrated salts and corrosion byproducts, creating a localized environment that further accelerated corrosion. Limited fluid movement beneath the deposits also prevented removal of aggressive species, allowing corrosion reactions to continue beneath the surface layer.

Potential Microbiological Effects

Seawater intrusion may introduce marine microorganisms capable of forming biofilms on internal pipe surfaces. These biological layers can influence local chemistry and create microenvironments that contribute to microbially influenced corrosion



Figure -4 Longitudinal view of the carbon steel spool illustrating severe internal corrosion buildup. The accumulation of corrosion products has considerably restricted the internal diameter. Stratified corrosion layers consisting of porous FeOOH outer phases and darker magnetite-rich inner layers are present. Pitting cavities beneath tubercles indicate localized under-deposit corrosion.

(MIC). Although microbiological analysis was not performed during this investigation, the operating conditions were consistent with environments where microbial activity may contribute to corrosion processes.

Hydraulic and Structural Implications

The buildup of corrosion products had a significant effect on the hydraulic performance of the pipeline. Measurements indicated that the remaining open flow passage had been reduced to approximately 30%-50% of

the original pipe diameter. This reduction corresponds to an estimated flow area loss of approximately 75%-90%, which can dramatically alter internal flow behavior. As the available cross-sectional area decreases, fluid velocity increases for the same flow rate. Increased velocity and turbulence may elevate wall shear stress and enhance oxygen transport to exposed metal surfaces.

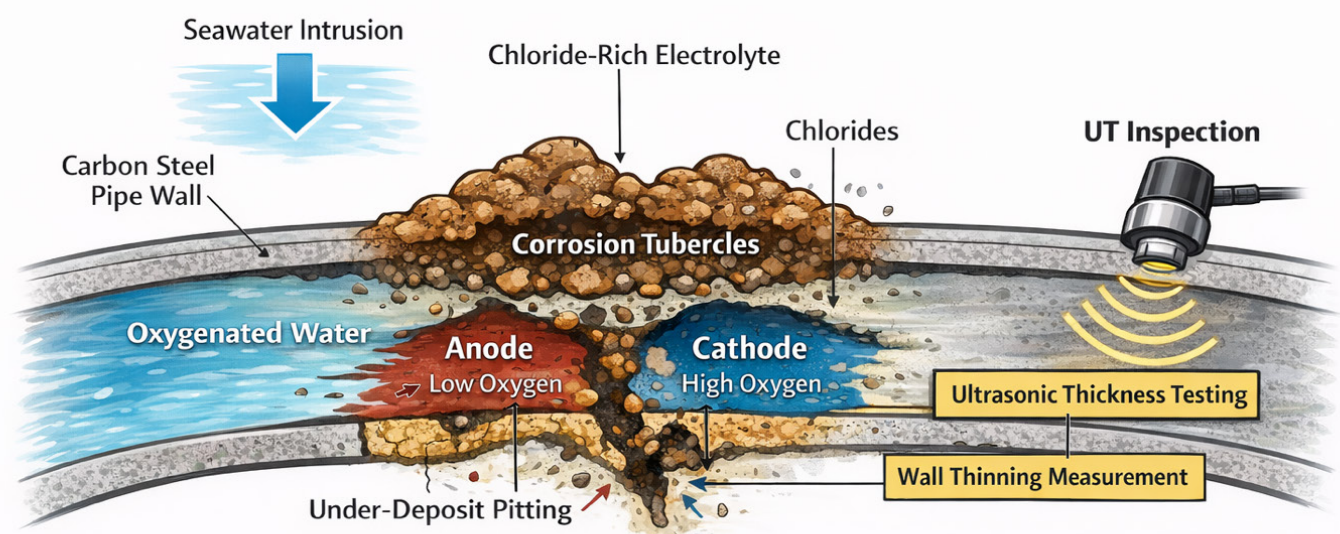
These changes can destabilize corrosion deposits and expose fresh metal to the electrolyte, allowing corrosion processes to continue and potentially accelerate.

From a structural standpoint,

localized corrosion reduces the remaining wall thickness available to sustain internal pressure. The integrity of the pipeline therefore becomes governed by the minimum remaining wall thickness, rather than the average wall thickness across the pipe.

Role of Non-Destructive Testing (NDT)

Non-destructive testing plays an essential role in identifying internal corrosion and monitoring pipeline integrity without interrupting operation.



Mechanism of Localized Corrosion in Carbon Steel Pipelines Following Intermittent Seawater Exposure

Figure 5. Simplified schematic illustrating localized corrosion development in a carbon steel pipeline exposed to intermittent seawater intrusion. Corrosion deposits create differential aeration conditions that promote under-deposit pitting, while ultrasonic thickness testing is used to detect localized wall thinning.

Ultrasonic Thickness Measurement

Ultrasonic thickness testing (UT) is one of the most widely used methods for monitoring internal corrosion in carbon steel pipelines. The technique works by transmitting high-frequency ultrasonic waves through the pipe wall and measuring the time required for the signal to reflect back from the internal surface. This measurement allows inspectors to determine the remaining wall thickness and identify areas of metal loss.

In pipelines susceptible to localized corrosion, UT measurements are typically performed at predefined monitoring points. Areas near flanges, low points, bypass connections, and other stagnation-prone regions should receive particular attention, as these

locations often experience accelerated corrosion.

Phased Array Ultrasonic Testing

Phased array ultrasonic testing (PAUT) provides additional inspection capability where corrosion damage is irregular or localized. By steering ultrasonic beams at multiple angles, PAUT allows inspectors to evaluate larger areas of the pipe wall and better characterize corrosion features such as pits and cavities.

Visual and Remote Inspection

When pipeline sections are removed during maintenance, visual

inspection of the internal surface can provide valuable insight into corrosion morphology. In some cases, remote inspection tools such as borescopes may be used to examine internal surfaces without dismantling the system. Combining these inspection techniques allows operators to better understand corrosion progression and identify high-risk areas requiring further monitoring.

Risk-Based Inspection Approach

In systems where operational conditions may fluctuate, inspection planning should follow a risk-based inspection (RBI) approach. RBI methods evaluate both the likelihood of corrosion occurrence and the

potential consequences of failure to prioritize inspection activities.

In the case of pipelines exposed to intermittent seawater intrusion, corrosion risk increases due to chloride contamination and the potential development of localized corrosion cells. Inspection efforts should therefore focus on areas where corrosion is most likely to occur, including stagnation zones, flange interfaces, and sections exposed to repeated saline intrusion.

By integrating NDT inspection results with operational history and water chemistry monitoring, operators can develop more effective inspection strategies and allocate resources to the most critical sections of the pipeline.

Integrity Management and Mitigation

Preventing recurrence of such corrosion requires both operational control and engineering improvements. The most important measure is ensuring proper segregation between fresh water and seawater systems to prevent unintended mixing. Isolation valves, bypass controls, and operating procedures should be designed to minimize the possibility of saline intrusion.

Where emergency seawater use

cannot be avoided, the pipeline should be flushed with fresh water as soon as possible to remove chloride contamination and restore stable operating conditions. Design improvements may also help reduce corrosion risk. Minimizing dead legs, reducing stagnant zones, and improving hydraulic flow conditions can limit the formation of corrosion deposits.

In systems where intermittent exposure to saline water is unavoidable, internal protective linings may be considered to reduce direct contact between the steel surface and the corrosive environment.

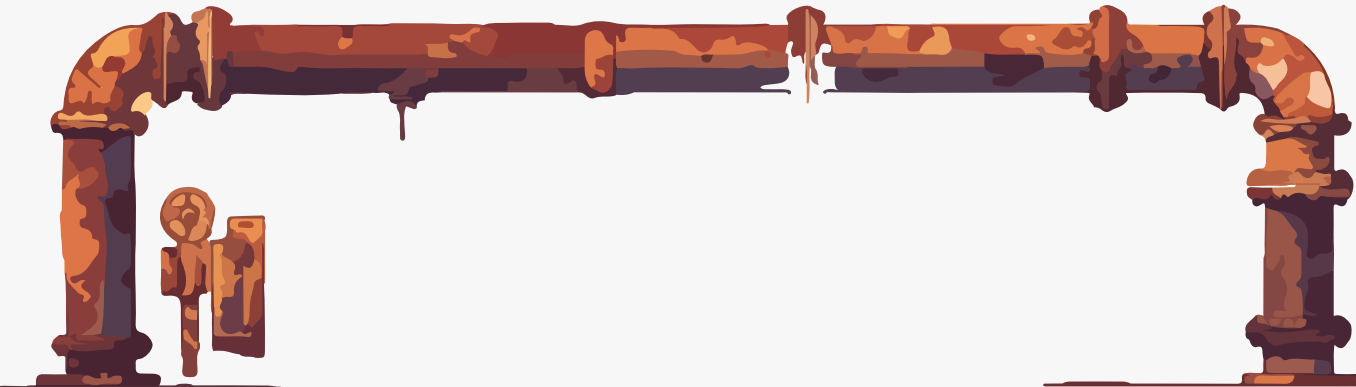
Conclusion

The case discussed in this article demonstrates how even short periods of seawater exposure can significantly influence corrosion behavior in carbon steel pipelines designed for fresh water service. Intermittent saline intrusion introduced chloride contamination that destabilized corrosion product films and promoted localized corrosion mechanisms including under-deposit pitting and differential aeration. Over time, these processes produced extensive tuberculation, severe flow restriction, and localized wall thinning concentrated in stagnation-prone areas. Such conditions present both hydraulic and structural risks to pipeline operation.

The findings emphasize the importance of integrating operational awareness, non-destructive inspection techniques, and risk-based integrity management practices to detect and control internal corrosion. By monitoring high-risk locations and responding promptly to environmental disturbances, operators can significantly reduce the likelihood of accelerated corrosion and extend the service life of pipeline systems.

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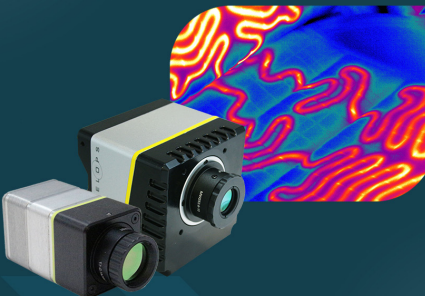
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