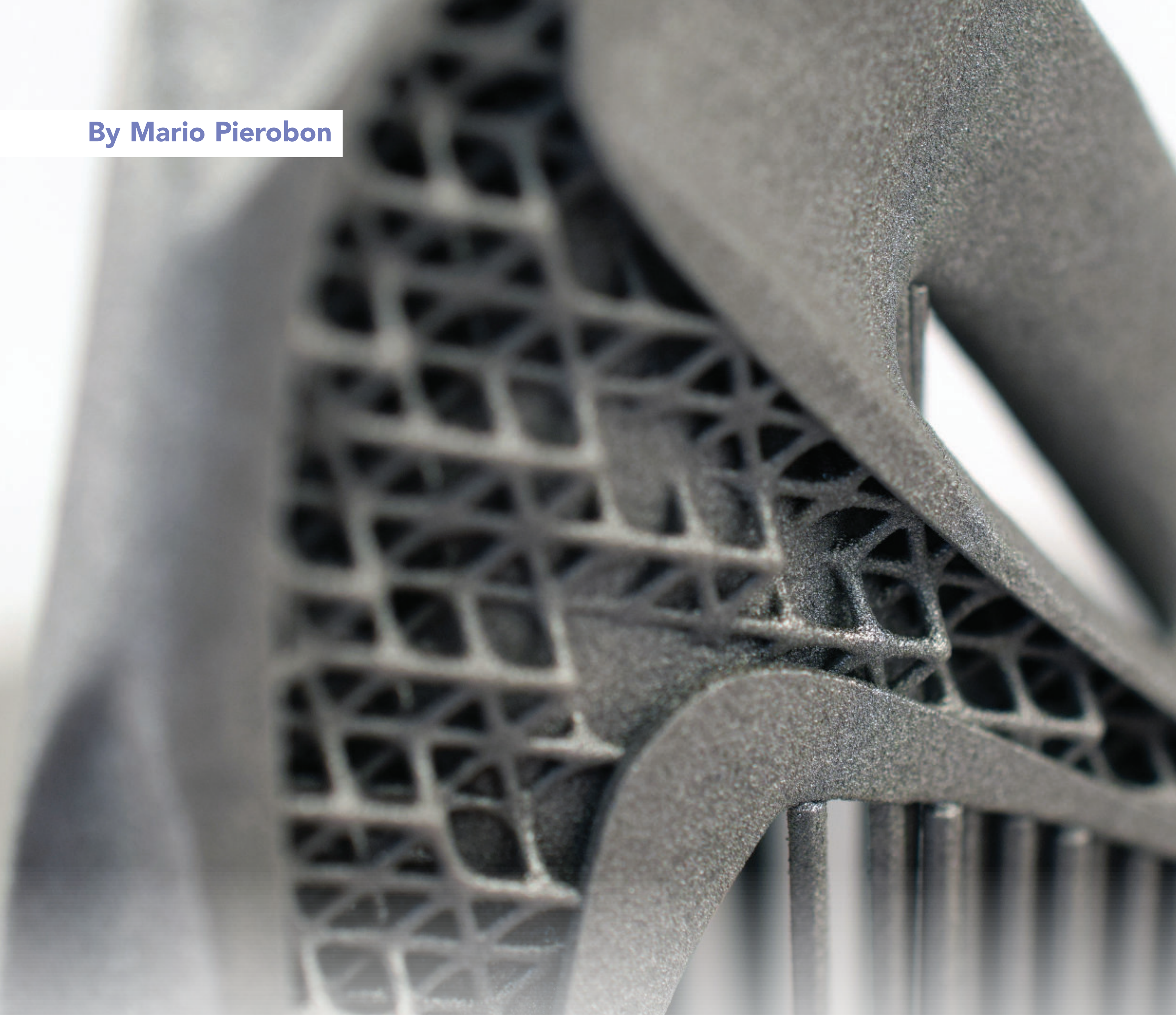


By Mario Pierobon

Parts Regeneration: Additive Repair is Coming of Age

Additive manufacturing has moved from a tool for prototypes and shop aids to a process applied, in defined circumstances, to actual hardware. For MRO organizations, the appeal is straightforward: components that are no longer procurable can be regenerated, and damaged metal surfaces can be restored with localized material addition rather than full replacement. What is perhaps less immediate is everything that has to happen before such a part or repair is released to service.

Processes such as selective laser sintering (SLS) and fused deposition modeling (FDM) have found a working niche in cabin component regeneration, where criticality is low to medium and dimensional tolerances are manageable with post-process finishing. Metallic processes, principally directed energy deposition (DED) and cold spray, are being evaluated for structural and heat-sensitive applications but remain considerably harder to qualify, particularly for the substrate adhesion, repeatability and mechanical performance data a design organization must produce.

The qualification requirements are the subject of sustained industry guidance. The Aerospace Industries Association's (AIA) Additive Manufacturing Working Group has published two documents of direct relevance: "Recommended Guidance for Certification of AM Components" and "Considerations for the Use of Additive Manufacturing in the MRO Space." Both are referenced throughout this article alongside operator accounts. This article illustrates how organizations are currently applying additive processes, how they test and qualify the resulting parts, what AIA's

This chart shows the difference between two of the most commonly used additive manufacturing technologies in aerospace: selective laser sintering (SLS) and fused deposition modeling (FDM). TPM3D Printing Technology chart.

All additive repair methods and applications are rigorously qualified to meet, and in many cases exceed, established performance and inspection standards, according to Delta TechOps.

guidance says about durability behavior and anomaly classification specific to AM, and how the regulatory chain from type certificate holder to repair station constrains what gets approved.

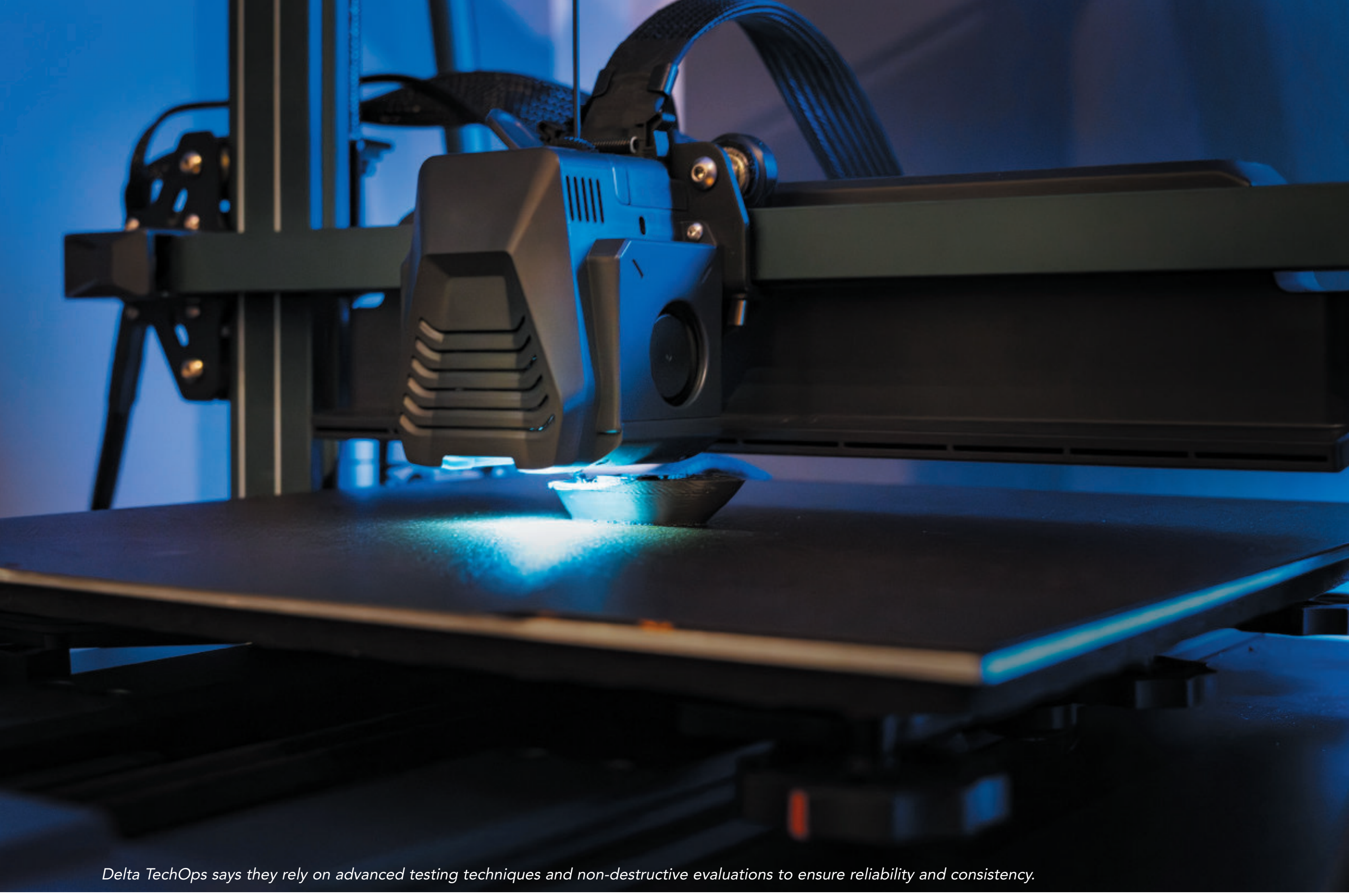
Additive Repair in Active MRO Environments

At Air France Industries KLM Engineering & Maintenance (AFI KLM E&M), additive manufacturing is currently used primarily to produce replacement components for original ones and to support cabin modifications, according to Jean-Baptiste Le Bideau, components industrial development director at AFI KLM E&M. "One example is the production of new power supply spacers with the same shape, size, and functionality as the original components. We also use 3D printing for repairs; however, in our case, this involves producing replacement components within equipment, rather than directly repairing the original component," he says. "A good example is the creation of new components for the cabin crew communication system. The technologies we currently use are primarily selective laser sintering (SLS) and fused deposition modeling (FDM)."

FDM and SLS are two distinct 3D printing technologies. FDM extrudes melted plastic filament layer-by-layer, making it highly accessible and cost effective. SLS uses a high-powered laser to sinter powdered polymers, producing robust, complex and isotropic parts without support structures.

For Delta TechOps, additive repair represents a significant advancement in aircraft maintenance. "We see it as a proven approach to improving durability, efficiency, and sustainability, guided by rigorous engineering, safety, and certification standards, rather than focusing on individual component details," a spokesperson says. "Delta TechOps is represented in the engineering and additive manufacturing fields on the Aerospace Industries Association's (AIA) Additive Advisory Panel. Additionally, we contributed to and influenced the drafting of guidance documents on additive manufacturing in the MRO industry."

Among the various additive manufacturing processes currently available, AFI KLM E&M has identified several ones that could potentially be used for repair applications within its maintenance activities, Le Bideau points out. "Some are specifically designed for the remanufacturing of complete components, such as SLS and FDM, while others are more suited to repair applications that involve material accumulation or deposition, such as directed energy deposition (DED) and cold spray. These processes differ from traditional repair methods, such as welding, in that they


Delta TechOps says they rely on advanced testing techniques and non-destructive evaluations to ensure reliability and consistency.

allow for highly localized material addition and, in the case of cold spray, without melting the material," he says. "This could make them particularly relevant for our aluminum components, where heat input must be limited to avoid deformation. However, these processes are complex to implement, especially from a component qualification perspective."

AFI KLM E&M is currently increasingly using SLS and FDM, both to regenerate certain damaged and non-repairable equipment parts and to manufacture alternatives to original equipment manufacturer (OEM) components. "Dimensional accuracy depends on the process used and generally requires additional finishing. One example is the cabin crew telephone unit, which is regenerated using FDM technology because the original component is non-repairable. These telephone units are then painted in different colors to match the interiors of customer cabins," affirms Le Bideau.

Testing in Additive Aircraft Repairs

Currently, Air France focuses exclusively on cabin components with low or medium criticality levels, explains Damien Jarriault, ALM team project manager of the innovation department. "This means that fatigue resistance is one of the criteria we consider, but it is not the primary factor guiding component design. When required by regulations, we perform mechanical tests in accordance with test plans issued by the design organization approval (DOA) holder and validated by a compliance verification engineer (CVE) to confirm the mechanical integrity of the parts," he says.

All additive repair methods and applications are rigorously qualified to meet, and in many cases exceed, established performance and inspection standards, according to Delta TechOps. "We rely on advanced testing techniques and non-destructive evaluations to ensure reliability and consistency, although we cannot share detailed technical comparisons," the spokesperson says. "We have collaborated extensively with a materials scientist at the Massachusetts Institute of Technology (MIT) on post-processing methods for components manufactured using laser powder bed fusion (LPBF) technology to match the properties of fused single-crystal components."

Durability and Damage Tolerance

AIA's report entitled "Recommended Guidance for Certification of AM Components" observes that durability and damage tolerance datasets can support a variety of end uses, economic needs for reliability, or individual design applicant design philosophy, and may influence the scope and type of data package developed. "Durability reflects a broader sustainment perspective that


From precise plastic adaptation to high-strength metal pressing tools, additive manufacturing offers numerous possibilities. Lufthansa Technik's Additive Manufacturing Center focuses on repairing, replacing and developing new parts. Lufthansa Technik image.

includes not only fatigue cracking but also corrosion, wear, and long-term reliability and service life considerations. Design data used in durability and damage tolerance analysis may be derived using a variety of industry or proprietary standard procedures with associated scale factors," the report states.

Durability and damage tolerance properties are prone to a high degree of variability, and, because of this, methods of analysis must account for scale and scatter, points out AIA. "The characterization of additively manufactured components may differ from that of conventional products. These differences should be considered before assuming that traditional product behaviors apply and must be understood by the design applicant," the report illustrates. "The durability and damage tolerance datasets must account for the components in the as used condition after all manufacturing, assembly and installation process steps."

AIA affirms that difference in AM features and artifacts that should be considered include such aspects as microstructure, geometric features, defect morphology and their distribution. Additional features include surface roughness, morphology, and variation as built and/or final component surface, inherent process anomalies, residual stress distribution and mitigation strategies, performance of chemical post processing and coatings, post printing chemistry, post processing impacts (support removal and powdering techniques, and component extraction) and thermal exposure history throughout the build.

"These features and artifacts unique to additive manufacturing may impact the following aspects of durability and damage tolerance analysis; corrosion, stress corrosion, wear and tribology, corrosion fatigue, stress fields, stress level and stress ratio effects, susceptibility to embrittlement, starting flaw size assumptions, multi-site damage scenarios, cracking patterns, crack growth rate and interaction, inspection type and capability, multimode behavior, scatter, time to initiation, damage coalescence, and microstructural mechanics failure. This list is non-exhaustive and will be subject to the verification and validation of the design applicant," AIA states.

Anomalies and Defects

Components made using additive manufacturing may exhibit certain internal or surface features that are anomalous compared to the basic structure, according to AIA in the 'Recommended Guidance for Certification of AM Components' report. "These features are an artifact of the manufacturing processes. The part requirements shall define acceptable limits for each of these anomalies and be documented in the type design and assured through the build quality plan. Only when these thresholds are exceeded is the anomaly then characterized as a defect and shall be submitted to the material review board (MRB)."

Some examples of material anomalies in additive manufacturing include porosity, i.e., the entrapment of small gas bubbles, common in metal solidification processes. Another anomaly is inclusion, which is a small particle chemically different from that allowed by the specification, according to AIA. "Lack of fusion is a condition in which fusion is incomplete, resulting in a lack of

GKN Aerospace says it has one of the world's largest additive manufacturing cells and dedicated centers in Trollhättan, Bristol, and Fort Worth. Their AM hubs are beacons of progress in additive manufacturing research and development enabling the production of large-scale aerostructures. GKN image.

homogeneity in the resulting material. Lack of fusion can happen in both powder and wire deposition processes," says AIA. "Balling is the instability of the molten material in the melt pool resulting in solidified spherical droplets on the build layer. This artifact can promote increased porosity and inclusions in subsequent layers."

Regulatory Pathway and Qualified Additive Repairs

Delta TechOps points out that additive repair is also conducted within a highly regulated framework, with oversight from authorities such as FAA and EASA. "Our approach prioritizes full compliance with these regulatory requirements, coupled with ongoing investment in our processes, facilities, and personnel to ensure safety and quality. The FAA also has a representative on the AIA working group for additive manufacturing," the spokesperson says. "We collaborated closely with them, along with other industry experts in developing the AIA documentation on Additive Manufacturing in MRO."

Le Bideau observes that there is no true generic approval applicable to MROs for qualifying an additive repair process. "In practice, a design organization must qualify the additive manufacturing process to be used — for example, DED or Cold Spray — and then design and approve the repair to be applied to the equipment in question. The repair is then performed by a Part-145-certified shop," he says.

To evaluate the use of additive manufacturing in the aftermarket, it is necessary to understand the relationship between the original equipment manufacturer (OEM) and/or design approval holders (DAH), air carriers, and MRO organizations, AIA observes in a document entitled "Considerations for the Use of Additive Manufacturing in the MRO Space." "The OEM/DAH designs a product and applies for a type certificate (TC); once the TC is approved and issued by the FAA, the OEM is referred to as a TC holder. The TC holder must establish a set of instructions for continuing airworthiness (ICA); this data is often, but not exclusively, published in maintenance manuals and provided to the air carrier," explains AIA.

The air carrier is responsible for all maintenance performed on an aircraft and maintaining airworthiness. ICAs are an integral part of developing a continuous airworthiness maintenance program (CAMP), created pursuant to 14 CFR Part 135 or 121, explains AIA. "Under a CAMP program, air carriers may allow the use of designated engineering representative (DER) approved repairs and/or alterations to aid in maintaining airworthiness, creating an opportunity for the introduction of additively manufactured components and/or parts in the aftermarket. It is therefore imperative that the DER be cognizant of the process-sensitive nature of AM part manufacturing as outlined in the AIA 'Recommended Guidance for Certification of AM Components' document, EASA CM-S-008 Issue 3, and other emerging regulatory framework documents," AIA affirms. "The repair shop (MRO facility) is required to adhere to all requirements of the CAMP. This includes having the OEM/DAH-generated ICA flow down to the repair station for execution of the maintenance or repair activity. The repair station may request and receive further information from the OEM/DAH through the air carrier or from the OEM/DAH directly."

There are numerous limitations in qualifying these processes, some of which are beyond the capabilities of MRO companies, especially for metal parts, affirms Le Bideau. "Demonstrating and justifying the key parameters required for qualification, including repeatability, mechanical performance, and substrate adhesion quality, is extremely complex. This requires extensive testing and detailed analysis of parts with widely varying materials, geometries, and damage conditions," he says. "An MRO can only produce parts that fall within the scope of its Part-145 certification. The manufacturing process itself must be validated through the organization's quality assurance system. Aircraft components manufactured according to European parts approval (EPA) regulations, however, are produced by Part-21G certified manufacturers, which allows them to issue EASA Form 1 certificates."

Artificial intelligence is increasingly being integrated in the aircraft MRO environment, and Delta TechOps is committed to promoting the use of data and analytics throughout the repair workflow, from inspection to return to service. "While AI supports our ability to anticipate needs and optimize processes, it is important to emphasize that AI provides insight, not a replacement, for expert human decision-making across all certified repair outcomes," affirms the spokesperson.

The Emerging Picture

The picture that emerges from operator practice and industry guidance is that where criticality is bounded and the failure consequence is low, as with cabin equipment produced by SLS and FDM, additive repair has already moved into production use. Where criticality rises and the process involves fusion or deposition of metal, the qualification path lengthens considerably: substrate adhesion, residual stress, surface-connected porosity, and the directional dependence of material properties all have to be characterized before a design organization can sign off a repair, and that characterization work sits with the design approval holder rather than with the repair shop alone.

The regulatory architecture gives a clear structure to the division of responsibility, but it does not amount to a generic approval for additive processes. Each repair is qualified against the specific component, material, and damage condition at hand, drawing on instructions for continued airworthiness, CAMP provisions, and either FAA or EASA oversight depending on jurisdiction.

Artificial intelligence has a role in that effort, principally in inspection and process analytics, but for the time being it informs rather than replaces the engineering judgment on which certified return to service ultimately depends. For the wider MRO sector, the practical guidance is to match the technology to the criticality at hand, invest early in the inspection and material data that any qualification will demand, and use AIA's published guidance as a working reference. AM

AIRCRAFT ACCIDENT INVESTIGATION & PREVENTION

GUZZETTI AVIATION RISK DISCOVERY

Be on GuARD!

GuARD specializes in:

- Air Accident Reconstruction
- Training Safety Professionals
- Emergency Response Planning
- Safety Audits & Surveys
- Technical Representation
- Crisis Communications
- Report & Document Writing

Are you prepared to deal with the aftermath of an accident ?

Accidents and serious incidents are relatively rare events that typically involve complex, challenging and stressful situations. Organizations may have little experience in dealing with these events, but they can significantly reduce the negative impact of them with preparation, training, and solid council.

We are "GuARD" ... Guzzetti Aviation Risk Discovery

GuARD is a business venture committed to improving aviation safety around the world through education, investigation, and consultation – while providing a means to feed our passion for aviation and to pass on a wealth of corporate knowledge regarding aircraft accident/incident investigation.

With over 35 years of experience to promote aviation safety, Jeff Guzzetti is taking his experience and training knowledge to the next level. He is not only a commercial-rated pilot, aerospace engineer, auditor, and instructor, but also an experienced air safety investigator and government executive.

(202) 600-5002 - Jeff@Guzzettiaviation.com