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SYSTEM DESIGN AND VERSATILE USE CASES APPROACH FOR A NEXT-GEN MODULAR FLIGHT TEST INSTRUMENTATION

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ABSTRACT

A few years ago, SDS presented the exploration of a new type of modular instrumentation that led to the realization of a proof of concept. This approach kickstarted the development of an innovative product addressing typical "pain points" of the Flight Test Instrumentation engineers. The purpose of this paper is to present the system design approach applied to this new product line. It will also demonstrate the broad range of use cases covered thanks to the versatility of this new concept and its standardized interfaces.

KEY WORDS

Instrumentation, system, wireless, modular, low SWAP

INTRODUCTION AND ADDRESSED CHALLENGES

Our era is marked by remarkable advances in data science, which now make it possible to more effectively capture and understand complex phenomena that often straddle multiple physical domains. Increasingly, these achievements rely on artificial intelligence algorithms to unlock new insights.

The aerospace sector, which relentlessly pursues efficiency and performance, is no exception, especially during development or production test phases, in-service monitoring, and investigations following unexpected events. Yet, the most sophisticated algorithms remain powerless without access to high-quality “fuel”: data. This essential issue is now commonly summed up by the mantra, “No data, no AI!”

Data acquisition in the aerospace industry is particularly challenging due to the wide variety of measurements required — such as temperature, pressure, deformation, or displacement — and the inherent difficulty of accessing certain measurement points. Areas of interest are often hard to reach, including moving components like landing gear or control surfaces, densely packed regions such as engine pylons, or remote and constricted locations such as wingtips or tail sections.

During development testing or in the investigation of anomalies, sensors and data acquisition systems must often be temporarily installed within aircraft structures. However, aircrafts are designed under multiple constraints and typically do not provide dedicated resources or provisions for such instrumentation.

Permanent installation of electronic equipment has been considerably facilitated within the avionics bay of civil aircraft through widely adopted standards like ARINC 600, which defines the physical (mechanical and electrical) interfaces. However, no equivalent standard exists for the temporary installation of data acquisition systems in other parts of the aircraft.

A further challenge for data acquisition systems is to minimize their intrusiveness. Data collection must not alter the aircraft's behavior, as this would render results unreliable or unusable. The total mass of the instrumentation system -including sensors, acquisition electronics, cabling, and power sources- must therefore be carefully optimized.
When temporary equipment is installed for production testing or troubleshooting, it must be fully reversible. No traces may remain after removal such as adhesives, surface alterations, or structural modifications like drilling.

In some cases, cavities in the aircraft structure —often designed to save weight— can be utilized to accommodate the data acquisition system. However, wired connections for data transmission, synchronization, or equipment management are frequently unavailable. Access to power sources (e.g., 28VDC) is not always possible or practical, especially where these networks serve critical aircraft systems.

Given these stringent constraints, available market solutions only partially address the needs or require trade-offs. The most compact data acquisition systems are often not modular, limiting adaptability, or fall short of state-of-the-art measurement accuracy performance. Wireless systems are typically insufficiently synchronized to guarantee temporal determinism and correlation of complex physical events. Most equipment is parallelepiped-shaped with custom mechanical interfaces, requiring the development and manufacturing of bespoke mounting hardware for each instrumentation zone.

In view of these challenges, how can we then offer a new acquisition system that empowers instrumentation engineers to gather the data necessary for aerospace innovation?

THE MICROMA CONCEPT

Drawing on feedback from the flight testing community and considering the previously described trends, Safran Data Systems set out to investigate breakthrough approaches for the next generation of instrumentation systems. Brainstorming sessions involving design engineers (hardware, software, mechanics, industrialization), product managers, commercial teams, and end-users (test and instrumentation engineers) from aerospace, automotive, and other industries generated a diverse set of innovative ideas. These multidisciplinary sessions fostered cross-pollination of experience and future vision, led by specialists in design and ideation to catalyze creativity and identify key concepts. One important line of inquiry was to reimagine the traditional parallelepiped enclosure. The central objectives were to facilitate installation, optimize daily operations, and minimize system intrusiveness [R1].

FACILITATING INSTALLATION

Most chassis and stackable systems on the market require instrumentation engineers to design custom mounting plates for integration into test vehicles, resulting in increased costs, longer lead times, and reduced adaptability.

To address this, the team identified the cylindrical form factor as a particularly promising alternative. The tubular design not only accommodates cylindrical connectors at both ends but also leverages standard mounting accessories (such as P-clamps, brackets, or straps) already present in vehicles for harnesses and piping. These inexpensive, reliable, widely available accessories come in various sizes and materials, enabling adaptation to local mechanical and thermal requirements.

Figure 1 illustrates several concepts developed by the design team; Figures 2 and 3 show, respectively, a CAD model created by the engineering office and a physical prototype built for a proof of concept (PoC) using rapid prototyping techniques. Ultimately, Figure 4 shows the final product definition [R1].

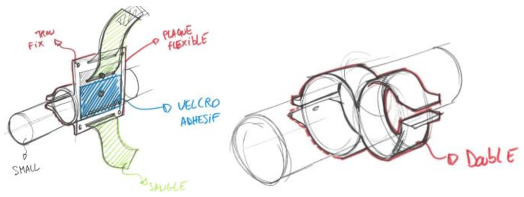


Figure 1: sketches of the early cylindrical shape concept

Figure 3: first 3D CAD model rendering

Figure 2: microMA Proof of Concept (PoC)

Figure 4: microMA Final Product Definition

MBSE METHODOLOGY

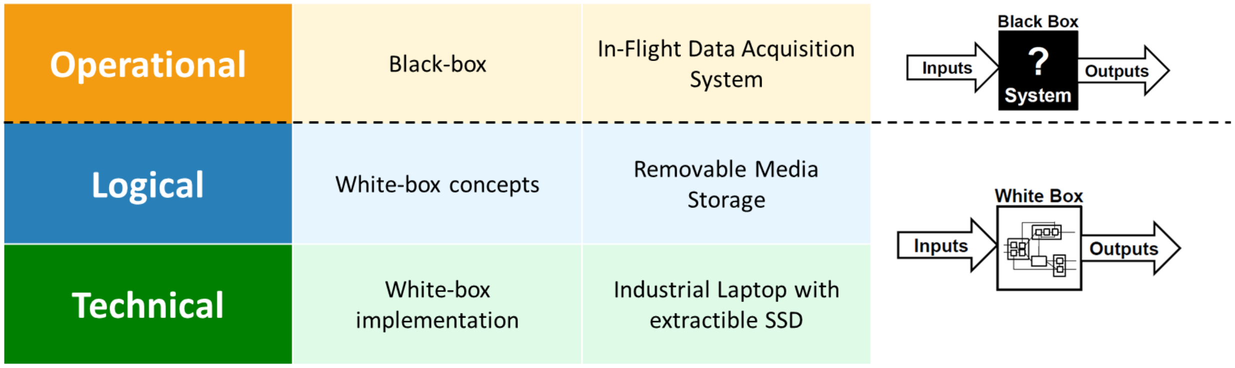
For the microMA development, Safran Data Systems has deployed an **MBSE** (Model-Based-System-Engineering) methodology to structure the requirements and functions to be addressed by the whole system, instead of designing separate components and thus losing the System capacity to address different use cases.

This methodology provides great benefits on the following points:

- Correct & exhaustive Customer Needs capture
- System Requirements Definition (Supplier Equipment Specification)
- Correct Definition of the System Architecture
- Allocation to the Components needs & specification

This approach allows to divide three layers of system Architecture (Figure 5) :

- **Operational Viewpoint** : System is considered as a "black box" and the analysis will focus on the following points : System lifecycle, Use Cases identification, operational architecture & sequences
- **Logical Viewpoint** : the purpose is to share a common vision of the conceptual system decomposition, or "white-box concepts". Architecture, sequences & modes are defined considering logical components.
- **Technical Viewpoint** : System is decomposed into physical components and seen as a "white box". The upper-level requirements are allocated to the physical components.



Operational	Black-box	In-Flight Data Acquisition System
Logical	White-box concepts	Removable Media Storage
Technical	White-box implementation	Industrial Laptop with extractible SSD

Figure 5: Example of the 3 architecture layers

The main purpose of the Operational Analysis is to identify the System stakeholders & use cases, to correctly assess and capture the System needs and functions allocation. The generic, high-level use cases considered by Safran Data Systems are shown in Figure .

At this stage, the System is still considered as a "black-box". The next step is to identify the System Functions needed to realize the "services" identified through the Use cases analysis.

Safran Data Systems made a complete MBSE analysis in the scope of the microMA project and therefore produced a generic functional architecture covering most of the FTI projects, as shown in Figure .

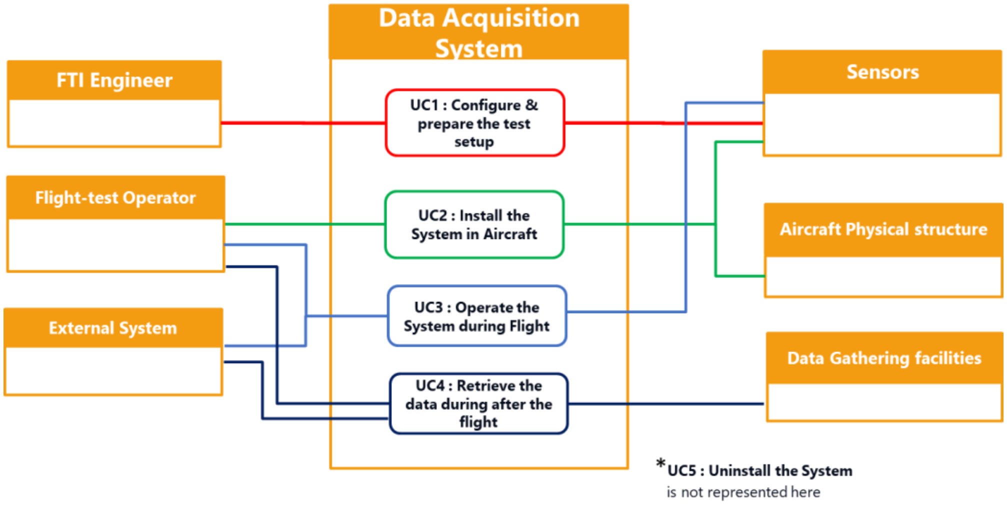


Figure 6 : System Use cases representation (simplified)

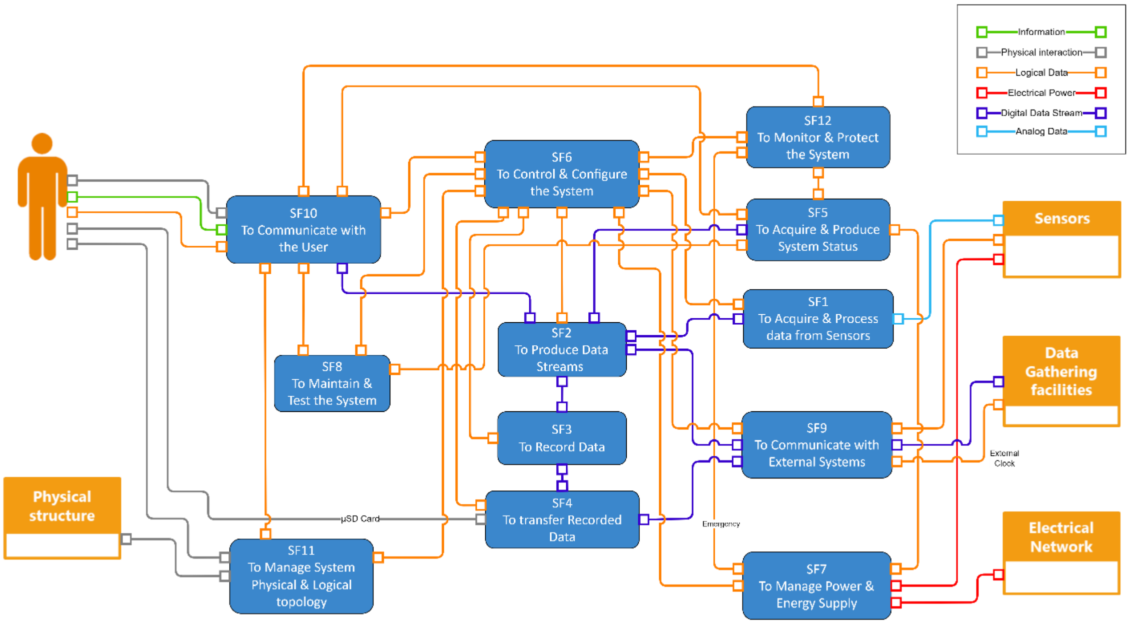


Figure 7 : Generic FTI System Functions

Based on this generic System functional architecture, the function breakdown and allocation to the logical components can be performed. The Figure gives an example of such breakdown for the **SF1** function and its allocation to the « Acquisition » logical component.

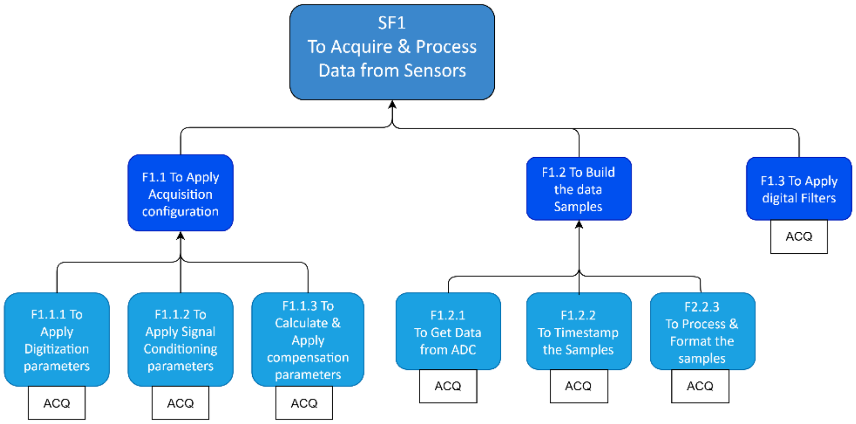


Figure 8 : Functional Breakdown of SF1 Function (example)

MICROMA USE CASES & ASSOCIATED SYSTEM ARCHITECTURES

The microMA acquisition system has been purposely designed to address the diverse and evolving needs of aircraft testing, certification, maintenance, and in-service monitoring. Its modularity, scalability, and compliance with aerospace standards allow it to support a wide spectrum of operational scenarios, from temporary troubleshooting missions to embedded predictive maintenance. The four primary use cases described below illustrate the architectural versatility and technical enablers of microMA.

1. Troubleshooting kit

In troubleshooting scenarios, rapid resolution of operational issues on an aircraft is essential. microMA is engineered for swift, cable-free deployment: technicians can quickly install the system on board, capture the required measurements with minimal preparation, and remove the equipment without any lasting impact on the airframe. This application hinges on several key design drivers: autonomous battery-powered operation (enabling use in locations without power sources), standalone data recording (eliminating the need for continuous connection with a ground station), very low intrusiveness (optimized mass, reversible mounting, no permanent modifications), and ease of installation/removal. The cylindrical form factor and standard mounting accessories enable seamless integration, even in hard-to-reach zones, supporting rapid diagnostic investigations while avoiding extended aircraft downtime. A typical architecture for this use case is illustrated in Figure 4.

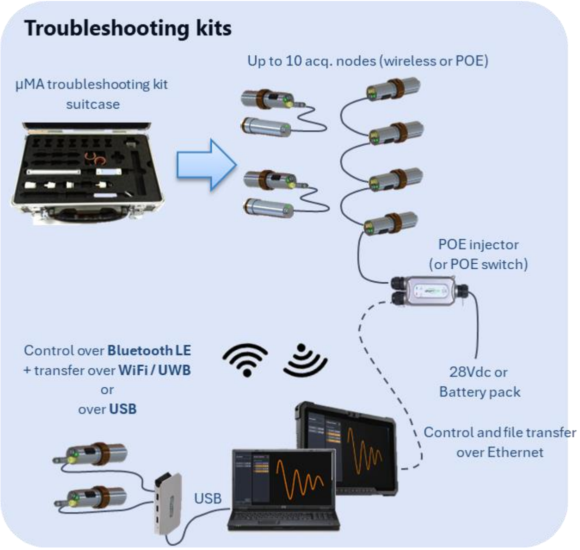


Figure 4 : Troubleshooting typical architecture

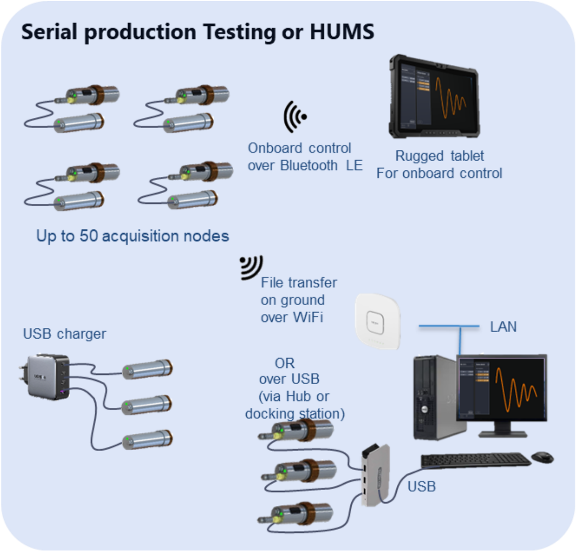


Figure 5 : FAL testing or HUMS typical architecture

2. Final Assembly Line (FAL) Testing

FAL testing encompasses acceptance and quality assessment procedures conducted prior to aircraft delivery. microMA serves as a versatile solution for recording various parameters—such as cabin acoustic environment, thermal mapping, and climate control performance—during these critical phases. The system's primary advantages for this use case are its extremely low intrusiveness, robustness for factory environments, and the ability to be centrally configured and controlled. Recorded data is automatically retrieved, providing traceability and an evidentiary record for manufacturers and clients in case of post-delivery quality claims. The architecture supports quick deployment and removal, ensuring production processes are minimally impacted while facilitating comprehensive verification of delivered performance. A typical architecture for this use case is illustrated in Figure 5.

3. Extension to Existing FTI

When integrated as a supplement to a full Flight Test Instrumentation (FTI) suite, microMA acts as a "satellite" node, especially valuable for last-minute or hard-to-access test points (e.g., using XMA-MDR as a primary system). This application augments the instrumentation network without requiring extensive reconfiguration, minimizing both logistical effort and aircraft exposure to intrusive installation procedures. Key enablers here include wireless connectivity (enabling placement in difficult locations), compatibility with prevailing data formats, centralized configuration to synchronize with primary FTI systems, and strong temporal synchronization (to maintain data integrity across the wider instrumentation ecosystem). The microMA's flexible architecture empowers test engineers to expand measurement coverage on demand, adapting to rapidly evolving test requirements. A typical technical architecture based on XMA system is illustrated in Figure 6.

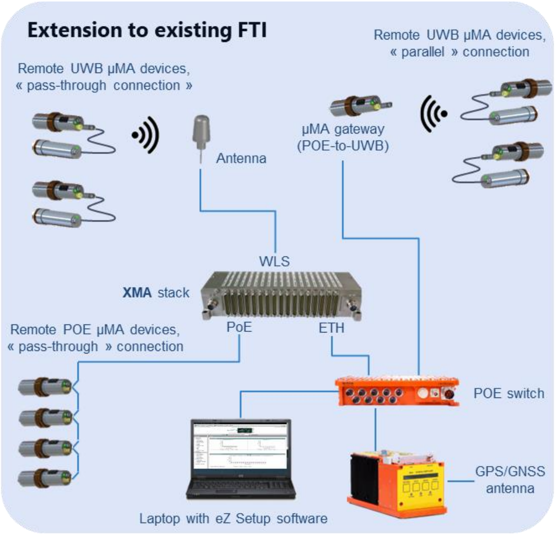


Figure 6 : Extension to FTI typical architecture

4. Predictive Maintenance

Designed for permanent installation, microMA becomes an enabler of advanced maintenance strategies by continuously monitoring operational parameters throughout an aircraft's service life. Its architecture prioritizes durability and robustness, supporting extended deployment in harsh environments with minimal need for maintenance interventions. Low power consumption and extremely low intrusiveness are essential to ensure that the system does not interfere with aircraft operations. Secure connectivity enables efficient transmission of health and usage data for advanced analytics, supporting early detection of aging or performance degradation in critical systems. The microMA's metrological fidelity ensures data quality sufficient for trend monitoring and precise diagnostics, allowing operators to optimize maintenance schedules and improve fleet availability. For this use case, the typical architecture is very similar to that of the FAL testing illustrated in Figure 5, except that the power supply may be permanent instead of battery.

MICROMA MAIN FEATURES & INTERNAL ARCHITECTURE

Despite its high level of integration, the microMA unit remains modular. This design choice is driven by the willingness to minimize the number of different parts to be owned while maximizing the number of use cases addressed by the solution. Therefore, the acquisition, the data handling and the power source are mechanically decoupled into 3 independent parts. The acquisition and the data handling are respectively managed by the acquisition cells (dedicated to the sensor type) and the controller cells (dedicated to the communication link: wired or wireless) that can be combined by the user according to his needs.

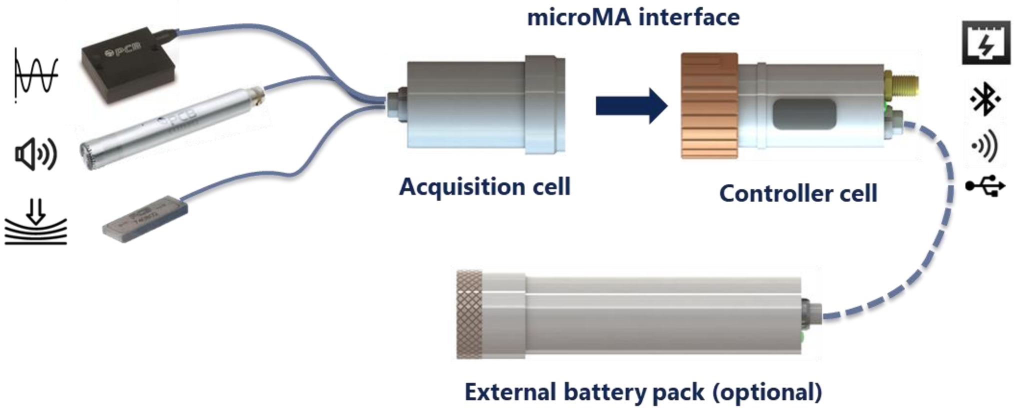


Figure 7: microMA modular architecture

The assembly/disassembly of the cells can be easily performed on the field without requiring any tool thanks to the locking ring and the electric connection performed without traditional connector. The microMA implements an innovative matrix connection based on a soft anisotropic conductive material that offers simplicity and reliability while inducing a good mechanical decoupling and geometric tolerance between the two cells. The overall architecture of the microMA and its interfaces between the cells have been patented.

Fitting electronics into a cylindrical shape is not always easy and most of the time not very efficient in terms of spatial efficiency. The original 3D origami-like electronic internal assembly of the microMA that offers a high level of electronic integration has also been patented. A microMA cells have a diameter of 24mm (0.94 inch) which makes them compliant with a large variety of off-the-shelf P-clamps already used in the aerospace domain. A complete microMA with its acquisition cell and controller cell is about 100mm (3.94 inches) long. Minimizing the intrusiveness of the flight test instrumentation also requires optimizing the weight: a microMA cell (acquisition or controller) is typically lower than 60g (2.1oz) which eases the installation as it does not require heavy mounting plates and most of all does not alter the behavior of the test vehicle.

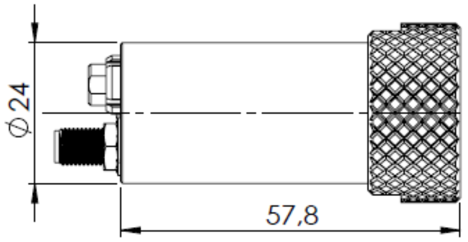


Figure 8: microMA wireless controller cell dimensions

As a battery powered device, the overall power consumption of microMA has been a hardline during the whole development process. The device offers a sleep mode which draws less than 20mW. In stand-alone recording mode, the power consumption is about 270mW and 650mW in WiFi transmission mode. The switching conditions between the various modes can be configured by the user based on remote commands or internal acquisitions like a given level of vibration or shock. As an example, a simple NiMH AA cell can support a 3-to-4 day test campaign including 6 hours of flight with continuous recording on the internal SD card of the signal coming from an IEPE accelerometer.

The metrology performance is another hardline that drove the microMA design. As such, the accuracy and signal fidelity are at the state-of-the-art of the digital acquisition units of the aerospace market. The analog to digital sampling rate is up to 256ksps and the typical accuracy is 200ppm of the full-scale range across the whole temperature range (-40°C; +85°C).

CONCLUSION

From the earliest sketches captured on paper boards during ideation sessions, a gradual and constructive process has enabled Safran Data Systems to develop and offer a new data acquisition solution founded on an original design and patented innovative technologies.

As a truly modular and scalable toolkit, microMA covers a wide range of use cases while addressing the many constraints faced by instrumentation engineers and adhering to the standards prevalent within the aerospace community. Beyond its core application in flight testing, microMA technology also meets data acquisition needs in production aircraft whether during Final Assembly Line (FAL) phases, acceptance flights, in-service health monitoring, or even during troubleshooting and maintenance operations.

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NOMENCLATURE

AI	Artificial Intelligence
ARINC	Aeronautical Radio Incorporated
FAL	Final Assembly Line
FTI	Flight Test Instrumentation
IEPE	Integrated Electronics Piezo-Electric
MBSE	Model-Based-System-Engineering
MDR	Modular Data Recorder
microMA	micro Modular Acquisition system
NiMH	Nickel Metal Hydride
SWAP	Size Weight And Power
SD	Secure Digital
SDS	Safran Data Systems
VDC	Volt Direct Current
XMA	eXtreme Modular Acquisition system