HOW TO RECONCILE COTS COMPONENTS AND TAILORED FUTURE-PROOF DATA ACQUISITION SYSTEM IN FLIGHT TEST INSTRUMENTATION?

Valentin BELAUD, Ghislain GUERRERO, Quentin LECOQ, Rémy PELLUAULT
Safran Data Systems
5, avenue des Andes, 91978 Les Ulis, France
ghislain.guerrero@safrangroup.com

ABSTRACT

During decades, FTI (Flight Test Instrumentation) systems were based on home-made or build-to-spec designs to address the specificities of each test article and the habits of each instrumentation engineers.
However, thanks to decades of standardization efforts, the flight test community progressively took benefits of the interoperability brought by the products and the instrumentation suppliers converted their offer into COTS (Commercial-Off-The-Shelf) product lines.
Despite the obvious benefits of the COTS approach (lead time, maturity, cost, maintenance, etc.), the focus on the mainstream needs have marginalized some features that brought a lot of value to some instrumentation engineers who now usually must complete their instrumentation system with custom items to meet their former expectations.
The aim of this paper is to present how FTI system based on COTS components can be tailored to embrace the uniqueness of each program and ensure future-proof capabilities, through modules that allow hardware and software customizations with a seamless integration into Safran Data Systems COTS solution ecosystem.

Index Terms - FTI, COTS components, HW/SW Customization, Future-Proofness

INTRODUCTION

Flight tests have always been a critical phase in the aeronautic field. The last step of a plane development, it consists of the gathering of as much data as possible regarding flight to ensure the behavior of the aircraft at its limits, and to meet certification requirements made by certification organism such as FAA or EASA.
It criticality lies in the fact that flight test takes place after the development phase, which represents a huge investment, and before the certification, which means the official authorization allowing for the operation of a type certificated aircraft, that represents the return on investment for the aircraft manufacturer.

Furthermore, flight tests are costly for the program:

- Dedicated test vehicles are allocated to flight test campaign,

- Planning a test campaign requires many resources (dedicated air corridors, dedicated airport lanes, fuel, etc.),
- Instrumentation should monitor a test vehicle in all flight conditions, whilst occupying minimal space and without modifying nominal behavior.

As a result, it is a massive burden upon the aircraft manufacturer's shoulders, who will logically try to reduce the tests campaign duration by any means and to decrease costs while not cutting any corner regarding quality.

To meet those needs, **the market has evolved drastically over the last decades**. Once *home-made* by aircraft manufacturers to address specific developments, **Flight Test Instrumentation (or FTI) systems got externalized to companies specialized in this specific field**, allowing aircraft manufacturers to focus on their core business.

At first, following the LRU (Line Replaceable Units) trend in aeronautics, **instrumentation was meant to meet one need specifically, and for every function was a specific DAU**. The architecture was centralized, and wires were the links between DAUs and sensors.

FTI components were *built-to-spec* to address each functionality, with great performances for the time being, targeting exactly what was needed. However, they were:

- costly because of non-recurring engineering effort induced by development, validation and qualification,
- risky due to the low maturity of the products that could lead to unexpected costs and delays,
- not always reusable from one test campaign to another, not to mention from one aircraft manufacturer to another,
- hardly maintained for the long run (or at prohibitive costs induced by obsolescence management plan, redesign and/or stock)

Driven by the civil flight test community appetite for performances, *time-to-certification* and cost reduction, FTI evolved tremendously to achieve a new way of doing flight test, with the upcoming of a decentralized architecture to reduce wires (thus reducing the size and weight of a FTI system), and then the emergence of modular DAUs. The next step is then obvious: **with the modularity came the idea of a generic COTS DAU.**

This *game-changer* has been progressively adopted by the Flight Test Community, thanks to its fair share of advantages, such as an extreme modularity, a great product maturity, a predictable and constant availability, a reduced cost, and a roadmap of improvements that ensure a constant support for users' needs.

Despite answering the market needs, it is still not a perfect solution. A COTS approach constraints the user to adapt its needs to fit what COTS equipment can offer. Furthermore, the user cannot guide the improvements roadmap, and is dependent on the COTS supplier regarding the upcoming features. Even worse, to add a feature without relying on the supplier, the user must add custom products upstream/downstream, which add costs, effort, and risks. This is what the industry should aim at: a sustained effort to compensate COTS cons, so that we can rely only on its inner strengths.

Safran Data Systems worked on this topic for years. Its XMA, is a modular DAU segregated in functional bricks (analog, digital, bus, video, storage, RF transmission,…), attached to a modular architecture open to the final user.

The XMA, usually integrated into a FTI system based on other XMAs, is a versatile tool, able to communicate with other equipment through a wired or wireless link and usable in various network topologies, such as star networks, or in a daisy chain. This flexibility empowers FTI system users, but there is still work to be done to mitigate COTS downsides.

Fig. 1: *Example of XMA modular Data Acquisition Unit with 6 modules and a power supply*

So, how can we provide users a FTI system based on COTS components such as the XMA - that can be tailored to embrace the uniqueness of each program and ensure future-proof capabilities?

A FIRST STEP TOWARDS HARDWARE CUSTOMIZATION

As said earlier, the XMA enables users by offering a brand-new architecture, flexible in design due to its wide modularity, and flexible in practice due to its network capabilities. It can be used for various cases, and in different configurations to match what users *generally* need.
But what of specific use cases, not fully covered by a COTS equipment's interface?

This is where the PRO (for Prototyping) and the PRO/EXT (for Prototyping/Extension) modules are coming in handy. They were made to allow users to integrate freely their electronic (or 3rd-party electronic) into an XMA stack, making the most of the highly ruggedized environment (shocks/temperature) and benefiting from the DAU power supply.

On the one hand, the PRO module is a module with the XMA' standard dimensions. It is an empty module with access to the backplane's power pins to provide power supply from the DAU stack to the user defined electronics. On the other hand, the PRO/EXT is composed of a PRO module, alongside an EXT module. The latter gives more component height and I/O capabilities for the user electronics.

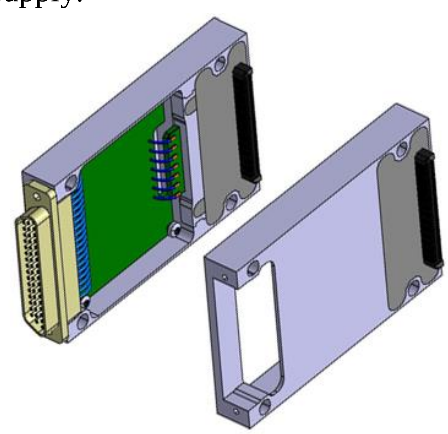

Fig. 2: *XMA-PRO & EXT showing the surface allocated to host 3rd party components (in green)*

Therefore, users can make quick hardware customizations to adapt the COTS equipment for extra requirements that would have no used in the portfolio.
The electrical and mechanical ICD is fully open and lets the user design and integrate its own electronic board by himself. A dozen of custom designs have been already successfully conducted by the XMA end users such as specific signal conditioning, generators, signal converters, … This hardware customization capability is also used by Safran Data Systems design team and partners to provide a solution to specific needs when low

quantities do not justify the complete development of a brand-new module. It is also used by Safran Data Systems for iterative prototyping of innovative features as illustrated by the following use case: Safran Data Systems is exploring the way to add Fiber Optic Sensing (FOS) capability to the XMA portfolio. To do so, a fruitful teaming with Safran Tech (Safran Group's central research center) and FiSens paved the way towards this goal.

Indeed, FiSens, a German start-up, developed one of the smallest Fiber Bragg Grating (FBG) optical interrogator on the market, small enough to be integrated into a XMA module.
But their interrogators were not designed for aerospace harsh environment, and not integrated into Safran Data Systems end-to-end instrumentation system. Both points were challenges to be tackled to successfully explore FOS.

Firstly, mechanical integration was the first roadblock encountered. As a modular product, it was mandatory to comply with the mechanical interface standard to keep hosting various type of modules in a single stack. This constraint would allow add-on capability to the thousands of XMA stacks currently in use and extend the combination of hardware configuration to meet future needs. Leveraging the mature mechanical design of the XMA, qualified and flight proven on numerous kinds of test vehicles, would be of great help to succeed in hosting and protecting the ultra-compact FBG interrogator technology designed by FiSens.

Fig. 3: *FiSens X100 FBG interrogator*

However, the volume offered by an XMA module housing is rather limited (50x80x11mm), as originally designed to high-end fine pitch electronics parts and not optical components.

Secondly, the electrical interfacing (powering/data communication) and the synchronization/time stamping was the second challenge encountered, so that we can harvest measurements that are consistently time aligned, and so easily correlated with other types of measurements and events.

To address these issues, Safran Data Systems, Safran Tech and FiSens applied an agile methodology, with an iterative roadmap. This has been eased by the fact that PRO and PRO/EXT were COTS modules, already designed for this kind of specific project. It allowed us to get straight to the point, and to focus on our challenges.

Thanks to the hardware customization allowed by the PRO/EXT modules, an ultra-compact **FBG interrogator has successfully been integrated into the XMA stack**, and combines a set of beneficiary properties:

- Dimensions (LxWxH) of only 50x80x20mm,
- A reduced weight of 160g,
- A low power consumption of 1W,
- A simultaneous measurement of all sensors (up to 30 FBGs),
- A high precision down to 1µƐ (@100Hz, σ)

Fig. 4: *1st aerospace grade FBG interrogator prototype with available FBG spectrum at 808-*

Characterization of the design in temperature, vibration/shocks, EMI/EMEC environment are currently in progress.

Compared to stand-alone FBG interrogators, the miniaturization and modular approach offers the following benefits:

- **Mechanical installation** in the test vehicle, whatever the content of the XMA stack, which leads to time and cost savings, and which gives a high degree of ruggedization due to the flight proven mechanical architecture of the XMA, compliant with the demanding environments of flight-testing,
- **Electrical powering** inside the XMA stack, coming from the PSI/PSS modules through the backplane, and therefore take benefits of a fully isolated, DO-160/MIL-STD704 qualified design,
- This **high level of integration** extends installation capabilities and offers more instrumentation channels for a given available volume,
- **Scalability**, as one or several FBG modules can be hosted in a single XMA stack whatever the form factor: CORE-8, CORE-16, ROTOR,

Fig. 5: *From left to right: a) XMA-CORE8 w/ 1 FBG interrogator/2 other modules; b) XMA-CORE16 w/ 4 FBG interrogators/2 other modules; c) XMA-ROTOR w/ 2 FBG interrogators/5 other modules*

- **Future-proofness and backward integration**, as the XMA-FBG module can be used with every XMA already in usage, and in every XMA flavor to come due to its standardized specs,
- **Versatility**, as we can mix fiber sensing measurements with heterogeneous data types in the same DAU: legacy analog sensors, digital, discrete, video acquisition, etc.,
- **Homogeneous connectors**, as obviously, the data communication of the XMA-FBG module uses a standard XMA microComp D-Type connector,
- **Fully integrated in Safran Data Systems instrumentation system**: configuration, synchronization, stand-alone or distributed architecture, wired or wireless network capabilities, standard compliant data stream (IRIG-106, IENA, etc.), on board recording, processing or even telemetry.

To generalize the approach, **it can safely be said that the PRO/EXT modules enable hardware customization of a COTS XMA** to allow users to embrace the uniqueness of each program. Thanks to its strengths that allow an iterative way of working through prototyping, **it permits the users to focus on their challenges while relieving them of mechanical, electrical and software integration** into the XMA ecosystem.

Moreover, **the standardized format guarantees retroactive compatibility** with already in usage XMA, whatever their format, **and ensures future-proofness**, as iterations of XMA DAUs are always based on modules. This flexibility, versatility and scalability gives a cutting edge to Safran Data Systems FTI system users.

SOFTWARE CUSTOMIZATION: ALREADY A FULLY-FLEDGED SOLUTION

Customization capabilities do not come only in hardware *flavor*. Software has also to be redefined constantly to meet users' needs, and Safran Data Systems has already developed a module that allows software customization: the OBP module, or *On-Board Processing* module.

Software is a key part of a successful flight test campaign. Indeed, every data is eventually processed, ranging from filtering to telemetry, including processing, displaying, etc. Running these processes in real time is even better, because the closest to the sensor, the earlier the information can be extracted from the acquired data, thus reducing the size of the latter. It is then easier to store and transmit more information to then analyze it on board or on the ground.

The OBP module is based on a Zynq *System-On-Chip* (or SoC), with a complete *Software Development Kit* (or SDK). It gives a fully embedded and ruggedized *Single-Board Computer* (or SBC), fully integrated into Safran Data Systems ecosystem, and allows the user to freely code its applications in C using inputs from the XMA backplane (*ie* other modules) or from its *own external* connector (*ie* I/O from 3rd party devices).
It then produces outputs that can be streamed to another module in the same DAU and/or to another DAU, to the ground, or stored in a recorder.

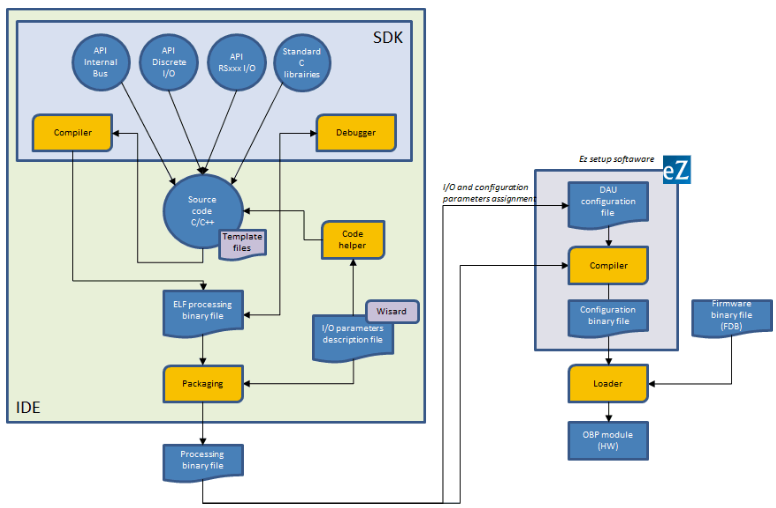

Fig. 6: *OBP Implementation Workflow*

As for the hardware customization capability, the software customization is packaged in such a way it can easily be used by the final user without requiring any knowledge of the XMA internal technology. This design flow is also used internally at Safran Data Systems, for design on request as well as by the innovation team to quickly prototype and explore new capabilities that could become future COTS features. Below are three examples illustrating the software customization capabilities of the OBP modules.

Fiber Bragg Interrogator

The FBG interrogator presented above was not only an example of hardware customization. It is also testament to the software customization brought by the OBP module. While the first step was to create a prototype interrogator able to handle one optical fiber, with up to 32 FBG, and integrated into a ruggedized and flight-proven stack, the command/control part and the digital interface with the XMA stack has been hosted in an OBP module.

By leveraging OBP capabilities (configuration, processing, internal communications through the backplane, external communications through its external connector), 3rd-party devices can communicate bi-directionally with the module using an Ethernet connection, a Serial line (RS422, RS485, RS232), or through its 24 GPIO. The prototype created before communicates through the PRO/EXT module external connector in RS485 and is controlled by the OBP.
Indeed, thanks to our implementation, the XMA can control the prototype (turn it on/off, change the sampling rate, read the spectrum, etc.), and collect data delivered by our interrogator to integrate them as standard XMA parameters. Data can then be saved into a recorder, sent to the ground via telemetry, or displayed with Safran Data Systems software suite, *eZ*.

Thanks to the fast software customization allowed by the OBP, we were able to swiftly assess our innovative technology in a real aircraft environment, on a Gulfstream GII owned by *Safran Aircraft Engines*
The aircraft, a flying test bed (or FTB), took off in July 2022 from Istres, France, with one of our prototypes to perform temperature measurements across the cabin.

This was a real achievement, given the limited time allocated to this project. It was possible thanks to unique tools like the OBP and PRO/EXT modules. The amount of customization offered by those modules gave Safran Data Systems a way to quickly obtain an airworthy prototype specifically tailored to our needs. Furthermore, **it showed that 3rd-party devices integration was quite easy, as any devices with an Ethernet, Serial or GPIO interface can become a part of the XMA ecosystem, ensuring future-proofness and flexibility to the XMA stack**.

Electrical Network Monitoring

The strong increase of electric actuators and propulsion systems in the aerospace field induces reinforced needs for adequate tools to monitor the electrical network during flight test campaigns. Here comes another use case where the OBP module customization potential shone.

A test set-up combining three-phase AC generators and DC generators was designed to be representative of the different types of electrical networks encountered in an aircraft. The current sensing has been done thanks to an innovative contactless sensor. The resulting eight analog signals were acquired using analog modules of the XMA DAU and then internally routed to the OBP module, which processed them on the fly. Among those processes, we implemented classical processing (min/max/FFT/THD/etc...), but also processing over one period, over one second, and correlated calculations between channels (phase, power measurements…).

We also added event detection. The results of the computations were sent back to the XMA architecture as derived measurements able to be used by any other module within the stack. In our case, the data were streamed over Ethernet in UDP packets which can then be fed to a recorder or a telemetry link, sent to another DAU and even be visualized in real-time thanks to decom and visualization software like Safran Data Systems eZ Processing.

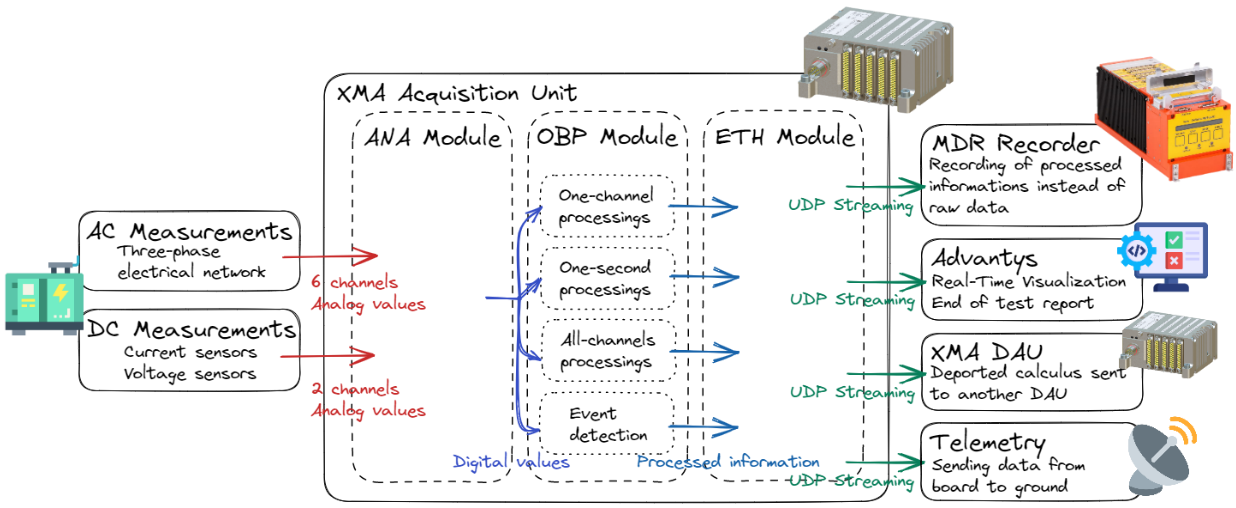

Fig. 7: *Schematic diagram of the electrical network monitoring use case*

One benefit of this experiment was to assess the behavior of the OBP module when processing high data rate measurements. Indeed, it has been used to process an input data streaming of 256kSPS (Samples Per Second), while computing every important parameter of an electrical network, including demanding calculus such as FFTs, 16 times per second, for each channel, over a window of 2048 samples. Moreover, the processor still had plenty of spare power to consider many more channels to be processed or more complex computation to be handled in serial or parallel mode. It enabled remote processing, which means heavy processing closer to the measurement source, making our DAU more responsive and decreasing the required bandwidth as the data is processed on the fly and only the useful data (*ie* the information created thanks to the code running in the module) is sent.

Lastly, **the project highlighted the OBP's inner strengths: as it is powerful and flexible, it enables us to quickly implement and test functions** that would generally take more time by the legacy design. **Versatile enough, it gives the user freedom to experiment, create and test functions that are industrial grade**.

Control/Command & Simulation Experimentation

The Space sector has tremendously changed over the last decades, essentially to a new market approach. This change implied a new philosophy that took over every level of the space industry: instrumentation has seen a new mixed approach, merging this field with avionics to reduce costs by centralizing data and functions.

To address these changes, the OBP module appears to be the optimal solution. It boasts excellent computing capabilities and is already integrated into a DAU stack, ensuring quick functionality while maintaining the required quality and environmental compliance for this type of device.

In order to explore the potential to host and run numerous complex algorithms, manage thousands of parameters while coping with real-time constrains driven by servo-controlled loops, an internal project lead by the *Innovation Cell* called “XRU project” was initiated.

It consists in simulating a classical SpaceX Falcon 9 trajectory, inside the OBP module. In parallel, and in a segregated way in the module, a flight model based on a basic Newtonian mechanical system runs. From an initial position, we computed the latitude and longitude of a rocket regarding its position in the earth referential. By comparing the computed results with the simulated trajectory, the speed and position parameters of the system are controlled through PID servo-controlled loops.

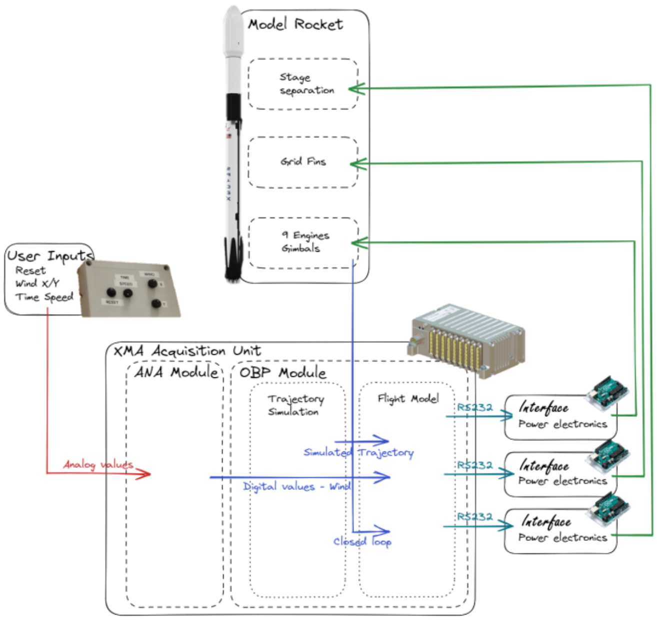

Fig. 8: *Schematic Diagram of the XRU PoC*

Furthermore, we created a model with genuine actuators (at a smaller size) such as grid fins and gimbals which were actuated by brushless electric motors. The OBP module controlled the actuators in a closed loop by sending regularly updated motor commands to an external power interface.

In addition, wind strength and direction were incorporated as user inputs to enhance the model's realism. These variables may disrupt the rocket trajectory and can serve as benchmarks for our control loops.

The XRU project displayed how our DAU can be used as a quick prototyping platform for avionics especially **by leveraging its modular architecture and its comprehensive set of COTS modules**. It also proved that the OBP module can run trajectory simulations, complex orbital mechanics, outputs and control/ command and is thus a capable SBC.

It also illustrate how the OBP can be used to experiment with unconventional ideas, such as avionics on an instrumentation stack.

CONCLUSION

This paper illustrates how Safran Data Systems has tackled the COTS components pain points: a lack of customization, a risk of relying solely on the COTS supplier improvements roadmap and a risk of being bound only to the COTS supplier portfolio.

To enable customization and safeguard future-proofness of the XMA, Safran Data Systems created a modular COTS DAU, and three modules: the PRO and the PRO/EXT, for hardware prototyping, and the OBP, for software prototyping. The combination of these allows users to quickly tailor their COTS DAU to embrace every single program they worked, work, or will work on.

Being highly integrated in the XMA stack, the OBP module takes advantage of other COTS modules (such as the ANA module) to gather data and do custom processing on it. **Its form factor, ruggedness and integration into Safran Data Systems' ecosystem empower users, allowing them to create custom modules from scratch** (as shown by the *Electrical Network PoC*), **interface the XMA stack with a 3rd-party device** (as shown by the *FBG Interrogator*), **and explore new use cases** (as shown by the *XRU PoC*). But much still awaits: Safran Data Systems' *Innovation Cell* tackles new applications, such as open standards, XMA integration into another ecosystem, or even AI algorithms.

As those projects proved, **the OBP is retroactively compatible with already existing stacks** due to its form factor and connectors. **It is also a way to meet users' needs** regarding software customization, **by giving the tools to tailor the XMA stack to embrace the uniqueness of each program**, thanks to the freedom implied by the module. Even more, **as the OBP is powerful, it ensures that future applications requirements will be met, which guarantee future-proofness**

REFERENCES

[1] Authors: Ghislain Guerrero1, Rémy Pelluault1, Jan Koch2, Wolfgang Schippers2, Philip Guehlke2, Christian Waltermann2, Nassim Salhi3, Didier Pohl3, Minh Chau Phan Huy (1:SAFRAN DATA SYSTEMS, 2:FISENS, 3:SAFRAN TECH): "*Fiber Optic Sensing: the challenges of miniaturization, ruggedization and integration to enhance flight test instrumentation capabilities*", ETTC (Nuremberg, GER), 2022

GLOSSARY

AI: Artificial Intelligence
DAU: Data Acquisition Unit
EASA: European Union Aviation Safety Agency
FAA: Federal Aviation Administration
FTI: Flight Test Instrumentation
I/O: Inputs/Ouputs
LCA: Low Carbon Aircraft
LRU: Line-Replaceable Unit
OBP: On-Board Processing
SDK: Software Development Kit
SoC: System on a Chip
SPS: Samples Per Second
SWaP: Size, Weight, and Power
XMA:eXtra Modular Acquisition Unit