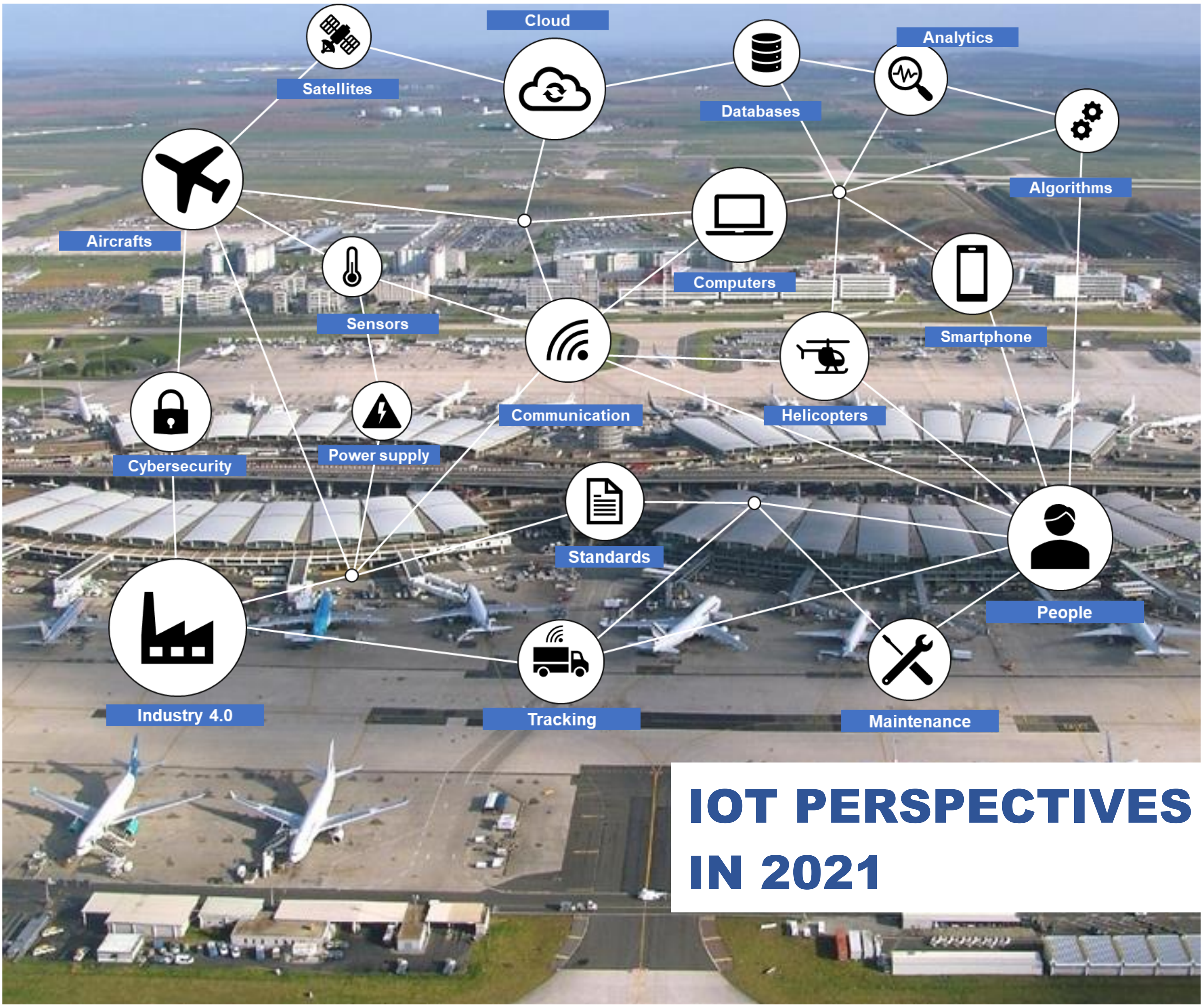

IOT PERSPECTIVES IN 2021

GIFAS

Groupement des Industries Françaises Aéronautiques et Spatiales

R&D COMMITTEE– Connected Objects & IoT WG

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Introduction

IoT technologies have brought about profound changes in many fields (Production, Energy, Health, Welfare, Logistics, etc.) thanks to the concomitance of several phenomena such as the miniaturisation of sensors, optimisation of energy consumption and emergence of new communication networks. An ecosystem of solution providers implementing these technological innovations in different sectors has developed and demonstrated numerous benefits for operational performance as well as for end-user satisfaction and also a better control of the environmental footprint of operations.

In this document, the GIFAS “Connected Objects and IoT” Working Group gives you its vision of the expected impact of IoT technologies of interest to the industry over the next 10 years, and then illustrates them with existing or planned use-cases, how technologies can be integrated at different stages of the life cycle of a component or system, from its manufacture, to its operational use and to its end of life, by identifying the benefits that can already be appreciated in terms of safety, efficiency, performance and environmental footprint.

Whether you are in the aerospace industry or a supplier of IoT technology solutions, we invite you to give us your feedback on the 10-year vision and to complete or enrich the use-cases.

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Foresight focus on IoT

1. Purpose

Aerospace is an industry of highly advanced technology requiring specific technical skills to transport people and freight worldwide in a safe environment. Design, manufacture and maintaining safe and efficient equipment and services are the core business of air transport stakeholders.

The aim of this part of the document is to consider technological trends related to Internet-of-Things (IoT) that may bring great added value to the future of air transport. With the support of GIFAS members and several start-ups, we made the IoT Technologies Trends Map to visualise when a technology will emerge and significantly influence the air transport industry. Space and military domains will be analysed in a further version.

2. What is IoT?

“The Internet of Things (IoT) describes the network of physical objects, or “things”, that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the Internet.” The definition of IoT from Wikipedia.org also shows that the purpose of IoT is to connect physical objects to internet that were usually unconnected. When the unconnected gets connected, vast amounts of new data emerge, along with potential insights and business value.

In this study, four pillars enabling the internet-of-things are considered:

- **Wireless networks** enable data transmission from the device to one network node and to internet. The network node may be a smartphone, router, ground antenna or even a satellite.
- **Energy harvesting** is the process by which energy is derived from external sources; ambient energy, such as solar, wind, thermal, vibration, kinetic, magnetic field, to store and power an electronic device.
- **Energy storage** is a technique to capture the energy produced at one time for later use to reduce imbalances between energy demands and production.
- **Sensors** are components of a device or equipment for detecting events or changes in its environment and sending the information to other electronics.

3. Scenario

To consider the impact of IoT technologies, four future scenarios have been envisaged. The scenarios describe a possible future where the trend of IoT expansion is confirmed and takes a major place in the air transport industry, manufacturing process, business standards and consumer’s market.

Wireless Avionics Network

- In 2030, all equipment will embed wireless capacities for non-critical communication with avionics.
- **Air transport business impact: Strong**
- Avionics is one of the core businesses of air transport and equipment monitoring is key to raising new service centric business.

Ground-Air Broadband Connectivity

- In 2030, digital continuity will be available on ground and on-board for all aircraft equipment or parcels being transported.
- **Air transport Business Impact: Strong**
- Avionics is one of the core business of air transport and digital continuity in real time is a major business trend in air transport.

Industry 4.0

- In 2030, all tools and equipment in factories will be monitored and controlled remotely.
- **Air transport Business Impact: Moderate / strong**
- Aircraft and equipment manufacturers, and even air carriers are industrial companies facing challenges in automating processes and optimising use of assets.

Worldwide Asset Tracking

- In 2030, all assets transported worldwide will be tracked and traced from manufacturing facilities to distribution centres.
- **Air transport Business Impact: Moderate**
- Aircraft and equipment manufacturers and even air carriers must monitor dispatch flows of valuable parts between manufacturing sites and maintenance hubs worldwide.

4. Method to build IoT Technologies Trends Map

Search, signal interpretation and map position

A signal is an event that hints at what the future may look like. A signal may be anything from a research breakthrough, law, investment, or general public behaviour.

The search for signals may be done in specialised academic online newspapers, tech-oriented blogs, venture capital news websites. The purpose of the search for signals is to highlight key technologies that have substantial business potential in the general IoT market or specifically in the air transport industry. To be able to record and share signals, it is recommended to characterise a signal with a URL link.

The interpretation of signals enables positioning technologies on the future IoT Trend Map, with the “Impact” of the technology as the vertical axis; how important the business potential of the technology will be, and “Relevance” as the horizontal axis, when the technology will significantly emerge.

Impact of the technology

The impact combines the notions of business potential with that of aeronautics. The business potential of the technology is based on signal interpretation of which may include applicable use-cases, business forecasts or investments. For instance, a signal for a technology enabling consumer-related use-cases offers great business potential with integration to billions of devices while investments backed by corporate venture capital is a signal for air operations applicability and business potential.

The impact of the technology is also related to the scenario applicability and thus the influence on the air transport industry.

Relevance of the technology

Information collected through signals also allows assessment of the level of maturity and when the technology will first be available or when it will be massively deployed. For this study, the relevance of the technology in terms of availability is based on when the technology enters into service in flight operations or is extensively applied to maintenance, manufacturing or other key activities.

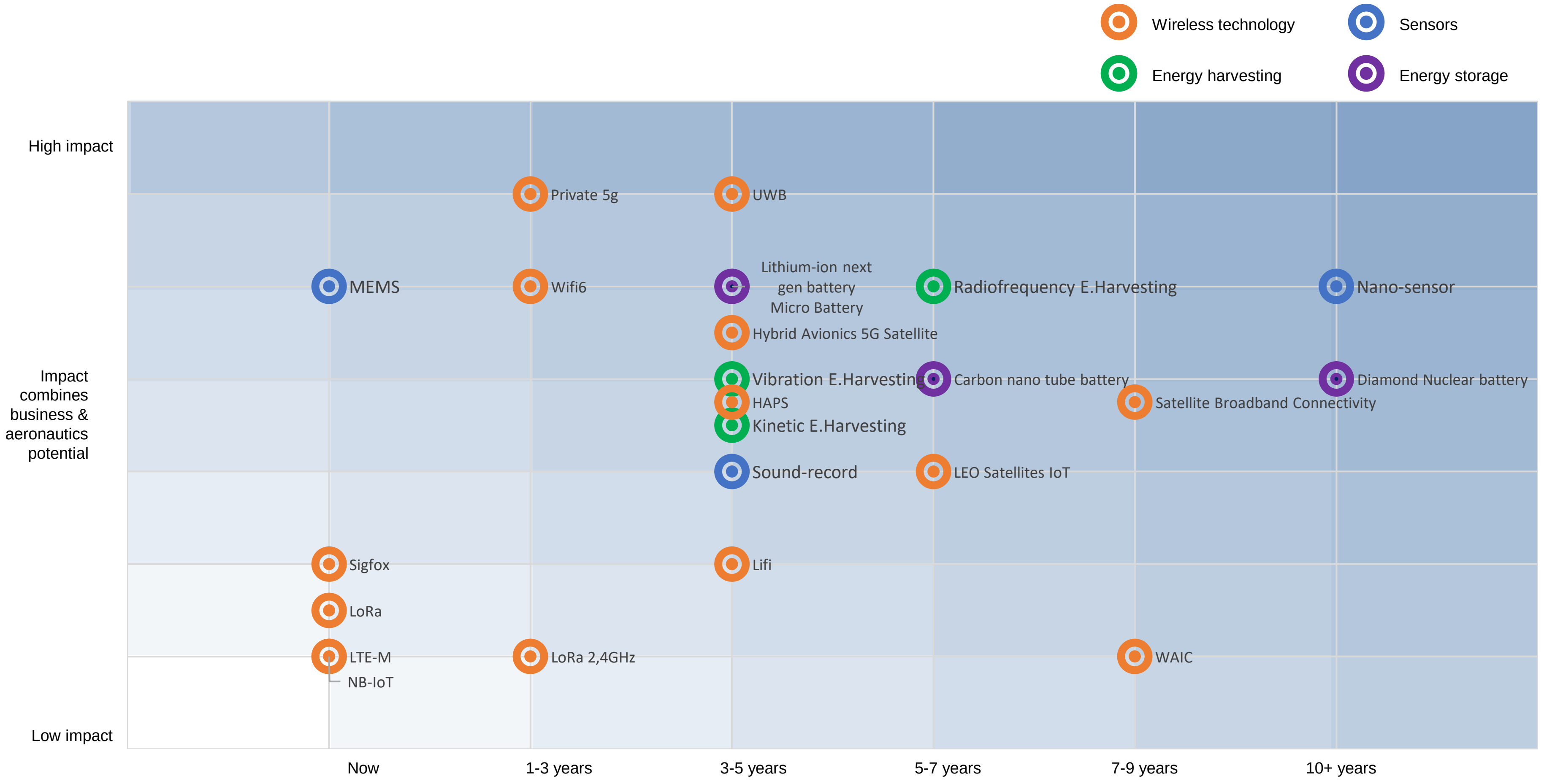
5. Future of IoT Technologies

The following section is the result of signal collection and further research done on key technologies and enablers of the Internet-of-Things world. The selection of IoT technologies may not be exhaustive and is an opportunity for air transport stakeholders to extend R&D scope of interest, assess applicability for air transport industry and eventually inspire new focus on the technology roadmap.

IoT Technologies Trends Map

The following IoT technologies trends map is based on the interpretation of signals and further research carried out to assess the impact and relevance of these key IoT technologies.

IoT Technologies Trends Map



IoT Technologies Details

Technology	Relevancy	Impact	Description	Explanation	Key Design Performance Indicator
Sigfox	Now	**Low**	Sigfox is a LPWAN technology that is deployed in 70 countries by local network providers. Interoperability between operators is automated and data is available on a single cloud infrastructure. Sigfox may be deployed on site with a base station in case of lack of coverage.	Sigfox has built strong partnerships with key stakeholders to deploy low-cost solutions massively. With international coverage and offer, Sigfox is a relevant technology for asset tracking.	Data rate: 100 bit / s Energy consumption: very low Range: 50km
LoRa	Now	**Low**	LoRa is a LPWAN technology that is deployed in 162 countries by public network providers and private network operators. Interoperability between operators and radio configuration change is not automated.	LoRa is extensively deployed for city-scale and facility-scale use-cases. LoRa experience in private networks deployment is valuable for « Industry 4.0 » use-cases.	Data rate: 50kbit / s Energy consumption: very low Range: 50km
LoRa 2,4GHz	1-3 years	**Low**	LoRa 2.4GHz is derived from sub-GHz LoRa that is deployed locally to cover private buildings or factories. 2.4GHz frequency band is open for use internationally (same band as traditional wifi). The technology enables (precise – cm) an indoor location system.	LoRa has a greater range of communication than Wifi but does not support interface with smartphones - technology adoption is low. Long-range to cover an entire aircraft is essential to addressing « wireless avionics ».	Data rate: 250kbit / s Energy consumption: very low Range: 100m
NB-IoT	Now	**Low**	Narrowband IoT (NB-IoT) is an approach supported by the world's three largest telecommunications equipment manufacturers. It has been designed to maximize coverage using existing base station infrastructure while keeping energy consumption and device hardware costs as low as possible.	NB-IoT is supported by Chinese corporations which represent the biggest country market. No international interoperability offer is available.	Data rate: 60kbit / s Energy consumption: low Range: 40 km
LTE-M	Now	**Low**	LTE-M is a simplified version of the LTE technology that underpins 4G mobile networks, the "M" signifying machine communication. It offers slightly higher data rates and lower latency than NB-IoT but requires more power to operate.	LTE-M is supported in USA and Europe by major network operators who may collaborate for international deployment. More data may be sent through LTE-M for advanced monitoring.	Data rate: 375kbit / s Energy consumption: medium Range: 40 km
UWB	3-5 years	**High**	Ultra-wideband (UWB) is a radio technology that can use a very low energy level for short-range, high-bandwidth communications over a large portion of the radio spectrum. It enables accurate indoor location systems.	UWB in smartphones is a life game changer by enabling digital keys for home/vehicle access, secure payment methods, smart home control, asset tracking (ex. Airtag). Adoption to hit nearly one third of all smartphones by 2025.	Data rate: 100 Mbit / s Energy consumption: very low Range: 200 m
Wifi 6	1-3 years	**High**	Wi-Fi 6 helps mitigate the issues that come with putting dozens of Wi-Fi devices on a single network. Wi-Fi 6 allows devices to plan out communications with a router, reducing the amount of time they need to keep their antennas powered on to transmit and search for signals.	Wifi 6 is also designed for low power devices. It may address « Industry 4.0 » use-cases to connect tools, manufacturing equipment and machines. International band and massive deployment are advantages to cover « wireless avionics ».	Data rate: 10 Gbit / s Energy consumption: medium Range: 50 km
Lifi	3-5 years	**Low**	Li-Fi technology uses LED light source capacity to adjust its brightness swiftly, allowing them to transmit a signal to be detected by an optical sensor in a receiving device to decode the information.	Lifi is starting to be implemented as a POC on board aircraft to reduce wire weight. Lifi is based on light and requires line-of-sight to operate.	Data rate: 3 Gbit / s Energy consumption: very high for RX / very low for TX Range: 10 m

Private 5g	1-3 years	**High**	Enterprises and organisations implement private 5g networks to get rid of wires and have access to broadband connectivity.	Sound, video and complex data may be processed thanks to broadband connectivity to deliver advanced monitoring and automation services in « Industry 4.0 » environment and eventually for "wireless avionics".	Data rate: 10 Gbit / s Energy consumption: High Range: 40 km
LEO Satellites IoT	5-7 years	**Medium**	Low-Earth Orbit (LEO) satellites fly just a few hundred kilometres above the earth, reducing both latency and the power needed for wireless transmission. Airbus and Boeing back different LEO constellations for IoT.	LEO constellations bring connectivity worldwide, even in remote areas, which is ideal for international deployment but may be considered as a back-up due to energy and subscription cost. 2024 is the target for LEO constellations to be fully deployed.	Data rate: 150 bit / message Energy consumption: medium Range: Earth to low orbit
Hybrid Avionics 5G Satellite	3-5 years	**High**	A ground network of LTE adapted cells enables broadband connectivity with airborne aircraft. If the ground network is not available, e.g., over the sea, a satellite back-up takes over. It requires avionics adjustments and ground network adaptation to be available worldwide.	It took 5 years for EAN to test and deploy the system across 2 airline groups in Europe. Deployment has been pushed back by a rebound in domestic air traffic in China. Gogo is willing to launch 5G air to ground connectivity in 2022 in Canada and the USA.	Data rate: 100 Mbit / s Energy consumption: very high Range: 100 km
HAPS	3-5 years	**Medium**	High-altitude platform station (HAPS) is a term for an aircraft that operates at high altitudes for extended periods of time, to provide services conventionally provided by satellites. HAPS can be used to provide both fixed connectivity for end users and transmission links between mobile and core networks for backhauling traffic.	The objective of the HAPS Alliance (including Airbus, Intelsat and Google) is to advocate the advantages of HAPS, which could be used by billions of people and devices in remote areas or where network infrastructure costs more to install.	Data rate: 1 Gbit / s Energy consumption: very high Range: 20 km altitude
Satellite Broadband Connectivity	7-9 years	**Medium**	Satellite broadband connectivity aims to provide low-latency, high bandwidth internet services globally, thanks to very large constellations of satellites in low orbit (LEO). Orbiting the Earth in around 100 minutes, LEO constellations provide a constant connection to the ground.	LEO constellations bring connectivity worldwide even in remote areas which is ideal for international deployment. Numerous companies such as SpaceX, Amazon and OneWeb plan to launch thousands of satellites. 2027 is the target for LEO constellations to be fully deployed.	Data rate: 200 Mbit / s Energy consumption: very high Range: Earth to low orbit
WAIC	7-9 years	**Low**	Wireless Avionics Intra-Communications (WAIC) is a wireless technology supported by major aerospace companies to reduce weight of wires between integrated avionics components and those installed on board an aircraft.	The business impact of WAIC covers only the safety and regularity of flight related applications (not passengers' applications). WAIC is a potential means of reducing aircraft wiring by 30%, using wireless devices to communicate data on radio frequencies instead.	Data rate: From 1 kBit / s Up to 4.8 MBit / s Energy consumption: depends on application Range: 100 m
Kinetic E.Harvesting	3-5 years	**Medium**	Kinetic energy harvesting is the process of converting environmental kinetic – wind, waves, vehicle movement, human motion, etc. – into electrical energy that can be used to power small and low-energy electronics.	At low-scale, motion energy harvesting is used for various applications such as pushing a button to send a small message. It is applicable for devices installed on moving equipment in a factory but also on-board where there is a wireless avionics network available.	Power density: 330 µW/cm3 Efficiency: 30%
Vibration E.Harvesting	3-5 years	**Medium**	Vibration electromagnetic energy harvesters convert mechanical energy produced by vibration to electrical energy to power small and low-energy electronics.	On industrial assets or rolling stock, vibration may be captured to continuously power sensors which eliminates the cost and disruption caused by the need to change batteries. This solution is an enabler for many rolling equipment monitoring use-cases.	Power density: 300 µW/cm3 Efficiency: 67%

Radiofrequency E.Harvesting	5-7 years	**High**	The ability to harvest RF energy, from ambient or dedicated sources, enables wireless charging of low-power devices. The RF energy harvester has the ability to maintain RF-to-DC conversion efficiency over a wide range of operating conditions. Battery-free devices can be designed to operate on demand or when sufficient charge is accumulated.	More and more radiofrequency harvesting solutions are deployed since RF power is available more or less everywhere around us.	Power density: 100 µW/cm3 Efficiency: up to 70%
Lithium-ion next gen battery & micro-battery	3-5 years	**High**	In a lithium battery, graphite is made of carbon, taking up more space than any other component. By swapping graphite for silicon, far more lithium ions can be stored in the anode, which increases the battery energy capacity. Solid state rechargeable SMD micro batteries have a 10-to-20-year lifespan and can cope with temperatures ranging from -40°C to +85°C.	Next-gen lithium batteries will replace current lithium technology in connected devices and may be applicable for electric cars. Billion dollars investments in this market are backed by automotive industry corporates.	Energy density: 2Wh/L Charging time: x3 faster Lifespan: x10 longer
Carbon nano tube battery	5-7 years	**Medium**	Carbon nanotubes are used as electrodes for batteries using intercalation, like lithium-ion batteries, to improve capacity. The principle is to move electrodes to a rigidly structured vertical array of carbon nanotubes, coated with an active material like lithium-ion, which can radically boost power density, energy density, charging speed and battery lifespan.	Fast-charge battery technology, combined with fast charging terminals enable the development of a fleet of vehicles that are always in motion in factories, logistics warehouses or urban areas.	Energy density: 3Wh/L Charging time: x5 faster Lifespan: x5 longer
Diamond Nuclear battery	10+ years	**Medium**	Diamond nuclear batteries run on the radioactivity of waste graphite blocks while Carbon14 n, the form of diamond-like carbon, is used for energy conversion. This technology would generate small amounts of electricity for thousands of years.	A diamond nuclear battery is for applications where it is either impossible or impractical to regularly change a battery, such as sensors in remote or hazardous locations or on satellites. Still at the prototyping phase, it represents a market of millions of devices with high added value.	Energy density: 10 mWh/L Charging time: self-charging Lifespan: thousands of years
MEMS	Now	**High**	Microelectromechanical systems (MEMS) are widely used for sensing many environmental parameters; temperature, humidity, vibration, light, strain…	MEMS are extensively used in the automotive industry, consumers electronics for a broad range of use-cases and applications. MEMS are embedded in almost all electronics devices.	Energy consumption: low Integration: basic electronics Harsh environment resistance: requires design adaptation
Sound-record	3-5 years	**Medium**	Sound record enables smart diagnostic solutions based on the acoustic analysis of machines. It consists of an IoT device recording the sound of the environment and a software solution to filter noise and recognize patterns of performance and behaviour leading to breakdown.	Sound record analysis and the services of real-time performance and health monitoring of industrial assets is starting to be deployed. Private investments and big firms (e.g., Amazon) support the technology.	Energy consumption: very high Integration: easy - no contact Harsh environment resistance: may be remote
Nano-sensor	10+ years	**High**	Nanoelectromechanical systems (NEMS) are a class of devices integrating electrical and mechanical functionality on the nanoscale. At this scale, chemical data may be detected such as particles in materials, liquid or gas.	NEMS are still in research phase but have a great potential in medical, defence and engineering industries, taking into consideration the present social trend of traceability in particular, without forgetting the pandemic context.	Energy consumption: low Integration: embedded in materials Harsh environment resistance: research phase

Out IoT Technologies' Trends Map

As explained, the selection of IoT technologies presented above may not be exhaustive. The aim of the trends map is to highlight emerging technologies with great business potential based on signals interpretation. There may be technologies with great business potential but are not emerging technologies. Similarly, there are technologies that are critical for the air transport industry but are not emerging technologies. Finally, the Internet-of-things definition and boundaries may vary from one person to another. That is why some technologies have not been introduced in the trends map. Below are some examples of technologies that were intentionally kept out of the map:

- Current / Voltage monitoring: not enough signals have been detected to consider its capacities as different from MEMS category and as an emerging technology integrated in IoT devices with significant business potential.
- Edge computing & AI: Edge computing is already deployed in IoT devices which are connected to the cloud for further computing and data processing. The need for more computing power embedded in IoT has not been detected as an emerging technology but more as a business trend which will be supported by major electronics manufacturers. AI will be addressed in a future specific version.
- Cybersecurity in IoT: Cybersecurity is a major technology trend that has great business potential. Signals regarding cybersecurity are actually related more to cloud platforms than IoT embedded applications.

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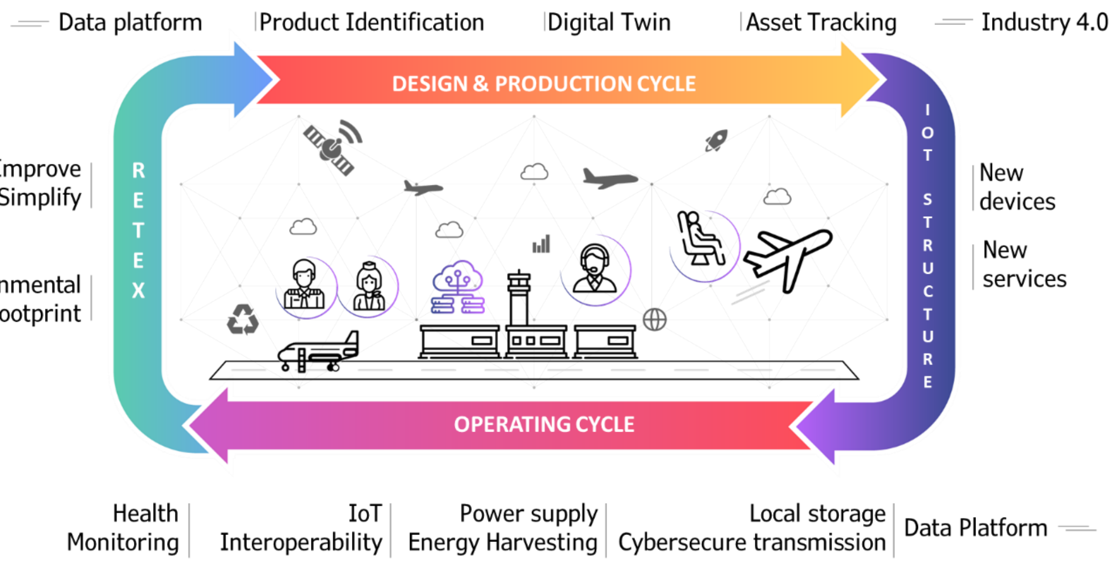
Opportunities around the complete life cycle

Technological innovations promise to push the limits of the imagination every day and demonstrate their ability to meet existing needs as well as create new ones to move towards ever more efficiency, safety, service, and ever more seamless experiences.

These advances cover all sectors. Our ambition is to describe and develop the Connected Objects and IoT ecosystem for Aerospace to address industry use-cases, including the following objectives:

- Identify, consider and challenge IoT technologies compatible with Aeronautics and Space.
- Implement digital continuity to cover the entire product lifecycle: design, production, transportation, logistics, installation, operations, MRO, withdrawal of service and recycling.
- Improve/disrupt existing operations, products and services.
- Bringing new features and services to operators, crews, pilots and passengers.



Expected solutions must comply with mechanical, hardware and software integration constraints and cover some requirements of the RTCA DO-160 (Environmental Conditions and test Procedures), DO-254 (Design Assurance for Electronic Hardware) and DO-178 (Safety Critical Software).

To illustrate how the above life cycle diagram can be translated into an individual experience for each component tomorrow, we can imagine the situation for some sample parts and what can be expected from IoT contributions and advancements in years to come.

The following topics will be illustrated:

Product Identification **Digital Twin** **Asset Tracking** **New devices** **New services** **Local storage**

Secure cyber transmission **Power supply** **Energy Harvesting** **IoT interoperability** **Health Monitoring** **Environmental footprint** **Improve/Simplify**

Use-case #1: IoT benefits for a passenger seat throughout its lifecycle

Topics:

Product Identification

Digital twins

Asset tracking

New devices

New services

Local storage

Health monitoring

Environmental footprint

Context

The following is a general diagram of a manufactured product for the aerospace industry.

We propose a case study based on the fictitious example of a **passenger seat** to illustrate the concepts appearing in grey.

Availability of IoT solutions along with a data platform can bring benefits at **all stages** of the lifecycle and we propose to illustrate them and to link them to the diagram.

Steps	**Benefits**
Design & Production Cycle	

- Design phase
  ○ Specifications are defined with all relevant characteristics (size, weight, use constraints, static load, dynamic load, expected cycling for hinge movements, recyclability constraints, an objective cost and the expected final appearance of the product.
- Prototyping
  ○ Preliminary tests are carried out.
  ○ Prototypes are sent to the customer and adjustments (iterations between equipment manufacturer and aircraft manufacturer) are made.
- Product certification/qualification
  ○ Blockchain proof of authenticity.
	- Product identification
	Record every information for further traceability in a digital health book which is filled with extensive information by recording tests conditions.
	- Machines Digital twins Automatic machine adjustments.
	➔ **Shorten design & prototyping phase**

• Production phase ○ Pre-established manufacturing process is followed and data are collected throughout the manufacturing process. A smart and connected device (companion) will follow the part throughout its manufacturing process and will allow pre-set the machines according to the results of the operations in the previous steps. ○ The following information is recorded: - Raw materials traceability. - Set points of all machines involved in manufacturing, including control machines with digital calibration certificates. - Process monitoring during manufacturing Manual/automatic quality control with test condition recordings and unit tests conducted on each part. Proof from the machine that it performed well and that it applied the solicitation profile during the test. - Information about tools that were used for assembly operations. (E.g., connected torque wrench that records tightening operation). - Handling parts, storage locations, list of people who handled parts and list of machines with the settings used (information collected from a MES). ○ Register a transaction in a Blockchain-type system with a digital certificate. Through this certificate, access to all parameters can be recovered.	• Automatic production machine adjustments. • Prevents mistakes (Poka-Yoke). • Complete digital twin of the product allows to record and relive the creation phase of the object itself. ➔ **No more loss in traceability** ➔ **Improve quality, efficiency** • Error-proof test phase. • Trusted results. ➔ **Improve reliability, safety**
• Logistics and supply chain ○ Trace of a component's location with atmospheric conditions (temperature, HR pressure, brightness, etc.) during transport and waiting phases. Packaging, storage, shipping. 1. Knowledge of the parts in the close environment (potential contamination), 2. Storage conditions (temp, HR, pressure, sunshine, magnetization, RF...) And storage time, 3. Handling conditions, movements, shocks and recording of these conditions over time, 4. Tracing routing points with a forecast of the next steps and position in real time. ○ Transfer of responsibility for the product on arrival to the customer (Blockchain). - Integrate component information into a larger database and creation of a tree view of the parent system (cabin interior in this instance).	• Real time information on transport, storage, and handling conditions as well as geographical position is provided through new devices with asset tracking capabilities. ➔ **Optimizing Logistics** ➔ **Less friction in the customer/supplier relationship**

IoT Structure

- During manufacturing process
    - Digital companions are attached to the seat and its subsystems prior to the final assembly throughout the manufacturing steps to record context and conditions at every step.
    - Those devices are "connected" and can trigger ad-hoc downstream operations in the process flow like pre-heating some machine, mould or pre-reconfigure a manufacturing cell according to the part characteristics at the previous step.
- Robots and autonomous systems can pick up parts by reading their digital ID or their companion's ID to optimise storage, move parts to appropriate places and optimise streams in logistics warehouses.

- Digital twin of the seat while being manufactured.
- Inform downstream operations of the imminence of a part arrival (smart manufacturing process).
- New devices (companions) as well as new services (predictive maintenance and just-in-time workshop reconfiguration) are proposed.

➔ **Improve operational efficiency**

Operating Cycle

- The seat is connected to some network to remotely monitor its status and its internal configuration.
- Data are merged from different sources: flight configuration (external), component history and health book (internal).
- The seat can monitor its internal condition and self-report to a monitoring system during flight.
    - Ex: seat back that refers its position to the crew for the take-off/landing phases. If the seat is equipped with actuators, it can position itself appropriately. The seat can control the seat belt tension and its fastening.
    - The seat can recognise if the armrest has been damaged and when.
    - Accessories presence can be monitored automatically.
- As the seat is "connected", it can update its firmware, reconfigure itself according to the passenger profile, propose personalised experience and even monitor passenger health.

- Better understanding of conditions that lead to damages with local storage.
- Implementation of Condition Based Maintenance with options: repair or change.
- C-Check and D-Check will be facilitated by a health monitoring system.
- By knowing the weight distribution of the passengers, one can balance the aircraft and save some kerosene.
- Improve user experience.

➔ **Cost savings**

➔ **Improve safety**

Retex

- At the end of the operation cycle, the individual mission profile can be extracted from the data platform that was filled during the lifecycle of every seat.
- Health book data are sent back to the seat and aircraft manufacturers for further analysis.
- Sample seats or all seats can report their usage level to designers.

- The seat records all the flights it has flown and can calculate its own carbon footprint.

➔ **Compute and ultimately limit environmental footprint**

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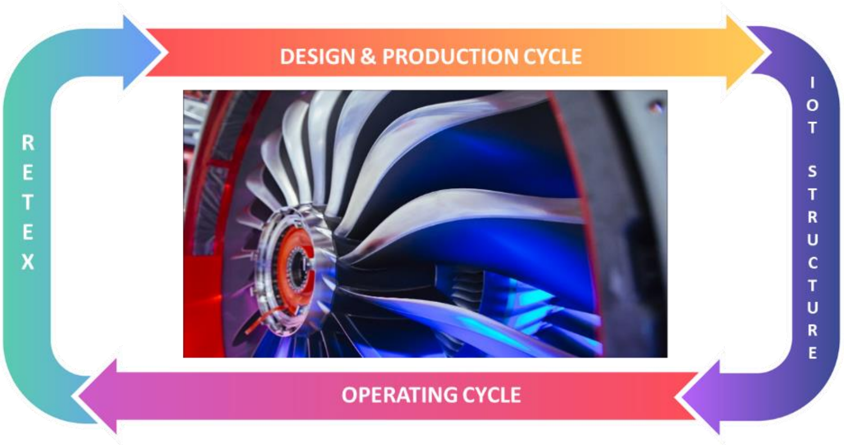
Use-case #2: Composite Fan Blade Monitoring



Topics

Product Identification

Digital twins

New devices

New services

Health Monitoring

Environmental footprint

Improve

Context

The use of composite structures in the aerospace industry is constantly growing and new applications are continuously being researched. This is mainly due to their superior stiffness to weight ratio, but also to their low electromagnetic reflectance and the ability to embed sensors and actuators.

If composite structures have many advantages, they do also have many disadvantages.

The cost of maintaining them is, for example, considerably higher and the behaviour of composites with respect to fatigue and crack propagation is not as well-known as it is with metal structures.

The damage mechanisms in aerospace composites need to be detected, evaluated, and even monitored continuously to avoid unexpected sudden failures. Based on the general diagram of a manufactured product for the aerospace industry, this can be achieved through the aid of a Structural Health Monitoring system that aims to combine advanced sensing technology with intelligent algorithms to diagnose the health condition of structures in real time.

The IoT system must be able to record, analyse and predict the loading and structural damage conditions of the composite blade to indicate information on the remaining life span or to perform a fault assessment.

Availability of blade IoT solutions along with a data platform can bring benefits at all stages of the lifecycle and we propose to illustrate and link them to the diagram.

In addition, the part monitoring solution through IoT could be combined with the engine configuration management and thus participate in the product identification and its tracking.

Composite Fan blades can exhibit problems such as micro cracking, delamination and porosity, all of which are difficult to detect, leading to a significant decrease in load capacity. They also have relatively low resistance to impact.

Current active monitoring techniques (visual inspection, ultrasound, eddy currents, acoustic emission, radiography, thermography and shear interferometry) are not suitable for on-board implementation since blade monitoring while in service would need to be done without human intervention.

Active surveillance would interact with the blade to continuously monitor its state of health and detect possible damage.

Specification

The design and suitability of a technique depends on its resolution and sensitivity, the ability to distinguish closely spaced defects and detect minute damage, which varies between techniques, but also, of course, the facility of the technique to be implemented for blade analysis.

For an active surveillance system to be successful, it must meet basic requirements such as: weight - size and installation - temperature vibration – storage - life duration – reliability – cost - maintenance.

In addition, system components must meet the requirements of altitude, humidity, vibration, waterproofing, sand and dust, magnetic effects, power input, peaks voltage, radiofrequency energy emission, susceptibility to transients induced by lightning, etc…, not to mention the potential corrosive, erosive and chemical environment problems.

Due to its rotating position, a self-power supply should be considered.

Steps	**Benefits**
Design & Production Cycle	
• Product identification Taking advantage of an intelligence source within the sensor, an additional configuration management function can be allocated by integrating the birth certificate of the part into memory, as well as its weight and centre of gravity to facilitate maintenance.	• Digital Twin shall integrate all the design data in order to have a very good traceability. Product identification • Record birth certificate for further traceability in the Digital Twin. ➔ **Improve configuration management and maintenance operation**
IoT Structure	
• During manufacturing process ○ Thanks to some built-in sensors, the system could measure the strain and temperature of composite structures, to monitor the curing process of composites and feed data to the digital twin.	• Digital twin of the blade while being manufactured. ➔ **Improve manufacturing process** • New services (predictive maintenance and life duration potential) are proposed. ➔ **Improve operational efficiency**
Operating Cycle	
• The composite Fan blade is connected to a maintenance network to: ○ Remotely monitor its health in real time, ○ Record potential shocks coming from fod (foreign object debris), quantify its impact and eventually leading to a maintenance action, ○ Indicate blade potential. • Thanks to its birth certificate, without having to disassemble either the fan blade or other engine parts, maintenance can be carried out; diagnosing composite panels repaired with glued-on patches, detecting fan blade delamination etc.	• Digital twin Better monitoring in real time of the part behaviour. • Energy harvesting could help to power supply the active surveillance system on the blade. • The ability to monitor a Fan blade in real time would increase safety, lead to lower maintenance costs, both in terms of reduced downtime and easier repairs, and optimise design. ➔ **Improve remaining useful life estimation** ➔ **Improve reliability, safety** ➔ **Improve maintenance operations** ➔ **Cost saving**

Retex

- The information recorded in flight and then analysed could lead to improving blade design and its manufacturing process by working on the weak points and reinforcing them.
- This same information could statistically strengthen surveillance models and improve the definition of digital twins.

- Improve all processes throughout the lifecycle by analysing collected data and context of use at every stage.
  - ➔ **Improve blade design and manufacturing process**
  - ➔ **Improve individual blade monitoring model**

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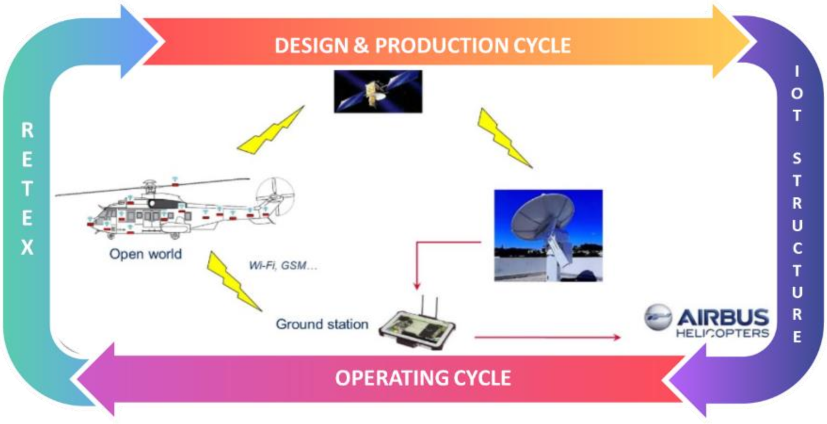
Use-case #3: Helicopter use-case



Topics :

Digital twins

Asset Tracking

New devices

New services

Local storage

Health Monitoring

Power supply

Energy harvesting

Environmental footprint

Context

Nowadays, the helicopter already proposes some radio communications means allowing data exchange gateways. In most cases, this can be done through wireless ground connections such as Wi-Fi (Wireless Fidelity), GSM (Global System for Mobile communications), with possible back-up links to Airbus Helicopters manufacturer. Another possible gateway could come from satellites; e.g., Satcom (Satellite Communications) or any future constellations but is currently less widespread due to industrial and communication associated costs.

Another important characteristic of the helicopter world is the maintenance burden. From the design phase, optimisation of maintenance is key. However, scheduled maintenance is based on fixed periods, based on conservative security margins, detrimentally affecting helicopter competitiveness. As the security margins of critical parts are the main drivers, one could also understand that anticipation of non-critical parts failures is not covered so well. To sum-up, main impacts are focused on financial expenses and availability. As a rough estimation, 30% of unscheduled maintenance tasks affecting helicopter availability could be avoided by failure detection anticipation (several thousands of euros per day for an Oil & Gas Airliner).

The solution would be to reconsider existing radio communications gateways in order to transfer all helicopter data to those in charge to carry out Condition Based Maintenance which is based on how the customer operates the helicopter.

To reach such a target and especially to anticipate any failures, the helicopter monitoring would be improved by new sensors, targeting all the systems for which any non-anticipated failure could lead to unavailability or have a financial impact. However, to avoid any competitiveness loss due to the integration burden and helicopter cost, new sensors should be autonomous in terms of communication and power supply. By doing that, the development of Network Connected Sensors would bring significant benefits to helicopters.

Usage examples of Network Connected Sensors

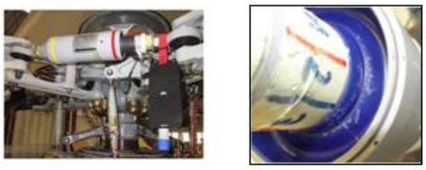
Drive system monitoring

Landing Gear Monitoring

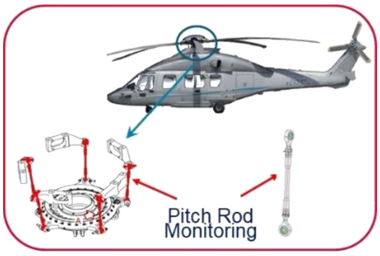
Corrosion – Cracks monitoring

Blades

Heating power optimization for de-icing
+
3D monitoring



Lead Lag Dampers Health Monitoring based on dynamic performance



Pitch Rod Monitoring

Steps	**Benefits**
Design & Production Cycle	
• Traceability along the manufacturing process. • All batches' characteristics are recorded.	• Digitalisation (e.g. RFID Tags): ➔ **Improve environmental footprint** ➔ **Improve operational efficiency** • Tracking of faulty batches. ➔ **High added value in case of incident or crash investigations.**
Operating Cycle	
• Logistics ○ Need of Spare parts under Customer responsibility.	• Asset tracking will alleviate customer burden by anticipating needs of spares. • Will allow optimisation of the Spare stores. (New services)
• Human Factor ○ Unpredictability of failure feeling. ○ Discomfort feeling. • Maintainability ○ Maintenance optimised depending on mission and flight profiles. ○ Consideration of safety margins. ○ Does not consider helicopter use, single maintenance tasks for all Customers. • For non or less critical systems, two possibilities: ○ Maintenance based on conditions or ○ With longest possible intervals. As this affects Helicopter Direct Maintenance Costs, the trend is to reduce this scheduled maintenance.	• Digital twin and Health monitoring will help the pilot and mechanicians to have a better knowledge of his helicopter. ➔ **Positive impact on the "Safety" feeling** • Allow maintenance considering how the helicopter is operated. Digital twin will enable New services for condition based maintenance. ➔ **Increase of life component in service** ➔ **Decrease of exploitation costs.** ➔ **Increase of Customer satisfaction** ➔ **Increase of helicopter availability**

Retex

- New functions
  - Current obstacles for deployment of new functions:
    - Impact on harnesses (data, power supply)
    - Impact on cost and weight.
    - If rotating parts (e.g. rotor, drive systems): bigger impacts.

- New devices will be power supplied by energy harvesting and thus allow new services like:
  - Shock detection.
  - Optimisation of heating dissipation for the de-icing function.
  - Capability of collecting Metadata would lead to advanced processing (e.g., Artificial Intelligence).
  - Video transmission (e.g., Emergency and Medical Services).
  - Part of the maintenance activities performed remotely by any specialised company.

➔ **New business opportunities and perspectives**

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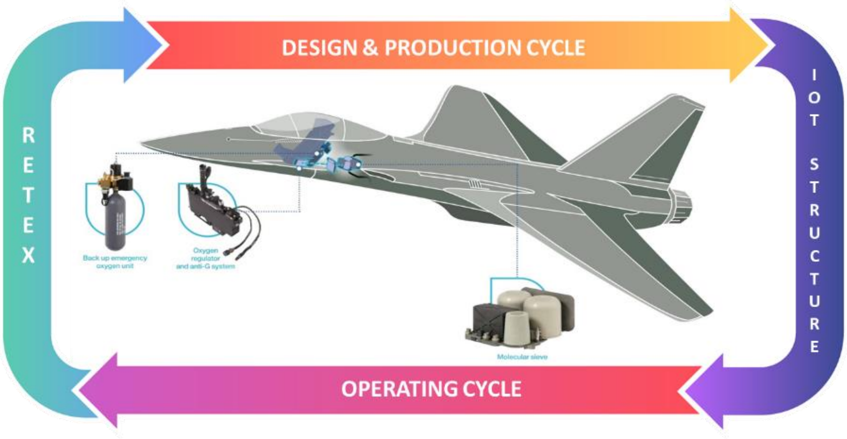
Use-case #4: On-Board Oxygen Generating System (OBOGS)



Topics

- Product Identification
- Digital twins
- Asset Tracking
- New devices
- New services
- Local storage
- Health Monitoring
- Environmental footprint

Context

The OBOGS is a mechatronic system that ensures the safety of the pilot but also the mission duration. This autonomous system generation produces unlimited oxygen enriched air on board fighter or training aircraft, to meet all the physiological needs (breathable gas and anti-G protection) of one or two pilots, for any long or complex mission. Without this system, the pilot would faint because of the altitude and the acceleration. Moreover, the mission duration would be limited by oxygen bottle autonomy.

The concentrator increases the oxygen level in the gas coming from the motor compressor using a pressure swing adsorption process. This technology is based on molecular sieves that separate the air elements. Regulators are integrated on an ejector seat or on the aircraft dashboard and give out oxygen-enriched air to the pilot through a mask with a variable rate depending on the altitude. This regulates the pressure and flow of gas that the pilot needs; oxygen enriched air to breathe and pressurised air for G-suit protection. The emergency bottle secures the oxygen provision in the event of failures or seat/pilot ejection.

Objectives

Using IoT solutions would avoid potential failures and reduce interventions thanks to predictive maintenance. It should meet physiological needs of the pilot more significantly, like in the automotive field with, for instance, driver monitoring alertness. This approach would make sure the mission runs smoothly.

Steps	**Benefits**
Operating Cycle	
• First hypothetic scenario: Oxygen system monitoring ○ On fighter aircraft, a black box is connected to a network to monitor the oxygen system with wireless sensors. ○ After the mission, the ground team retrieves data from the “black box” through a secured remote connection near the fighter aircraft. ○ The equipment logbook is uploaded to a private server/cloud.	• Enables alerts for a potential anomaly or maintenance operation through health monitoring. ➔ **Save costs** ➔ **Improve safety**
• Second hypothetic scenario: Pilot monitoring ○ To monitor the health of the pilot as closely as possible, wireless sensors are integrated into the flying suit and mask. ○ During the whole flight, the physiological data are registered on the black box. ○ An alert is sent from the “black box” to regulator if more oxygen is needed. ○ After the mission, the pilot data are retrieved on private server/cloud with wireless connection.	• IoT interoperability will help to respond better to the physiological needs of the pilot. • New devices will make new services possible for the pilot’s health monitoring. ➔ **Save costs** ➔ **Improve safety**
• If the constraints of mechanical integration and electromagnetic compatibility allow it, the “black box” could be integrated into the regulator.	➔ **Save costs** ➔ **Improve integration**
Retex	
• At the end of the mission, the data are retrieved on the private server/cloud for further analysis.	• Diagnose the regular anomalies will lead to optimising the next missions. ➔ **Ensure pilot safety**

When the technology, safety and cost will allow it, the data could be retrieved in real time to a ground command centre. A satellite communication could be used during the mission.

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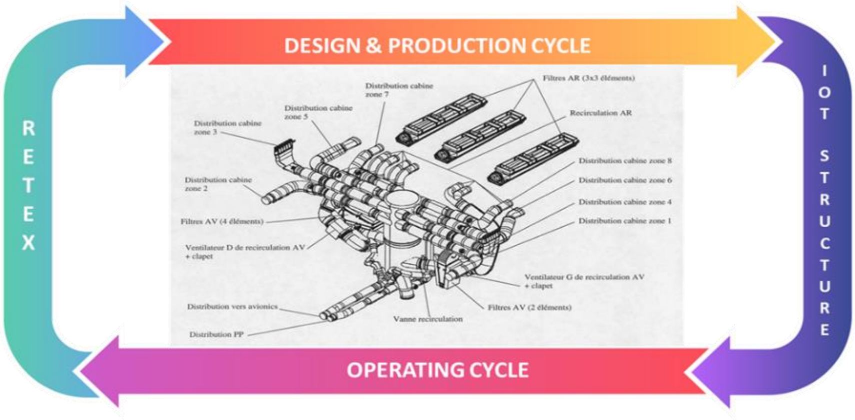
Use-case #5: Fluid Distribution use-case in an aircraft cabin



Topics

- Product Identification
- Digital twins
- New devices
- Health Monitoring
- IoT Interoperability

Context

As seen in the previous use-case, Fluid Conveyance can not only be vital, but is also a key aspect for the aircraft's maintenance. Made of hundreds of metres of ducts & pipes in a commercial aircraft, the fluid distribution reliability is needed at a high level for every level of the system: ducts & pipes, vanes & pumps, mixing units & filters, fittings, extractors & connectors.

Fluid conveyance systems reliability needs to ensure operability for:

- Operational conditions,
- Fluid variability & contamination,
- Recirculation & filtration,
- Ageing & cycling of use,
- Assembly, removal, and manual interventions (cleaning, …) in the system routings,
- Risks by operating the aircraft with fluid leakages.

Thus, the quality & reliability of fluid distribution is key, for both safety & operation.

As a typical use-case, Environment Control Systems (ECS) distribute filtered and tempered air into the cabin in order to maintain perfect conditions of comfort for the passengers, whatever the exterior conditions and by extracting any undesirable gases (CO_2, VOC, smells and odours from galleys, etc.).

Air distribution systems are made of:

- ECS « packs » designed to cool down the hot air extracted from the bleed air systems connected to the engines,
- Mixing units in order to mix different air sources,
- Ducting network for air distribution to the cabin, cockpit, maintenance & cargo areas.

Part of this air is recirculated after filtration while a remaining proportion is blown out.

In addition to the first level of requirements in terms of data to control the quality of fluid distribution during all flights' phases, safety raises the question of redundancy, which increases the key role of data acquisition & communication, even more so in fluid transfer systems operations. Needs for data acquisition & communication are numerous and are key technical enablers for improved operations and maintenance of fluid transfer systems.

Thereby, in the following table we will see how IoT & data management are core technological bricks to improve the reliability of fluid distribution systems and enable predictive maintenance of these systems by the adoption & integration of new technologies to provide additional measuring points at component and equipment level as well as being integrated at aircraft level.

Steps	Benefits
Design & Production Cycle	
• Identify parts and mark them at the manufacturing stage.	• Product identification Record birth certificate for further traceability in the Digital Twin. ➔ **Improve configuration management and maintenance operation**
IoT Structure	
• A "smart" and connected device as described in the Generic sensor use-case will contribute to the adoption & integration of new technologies at component and equipment level as well as being integrated at aircraft level.	• New devices integrated from scratch or on-demand will be linked to a wired or wireless network, ensuring IoT Interoperability They will be part of a data architecture and enable systems monitoring as well as feeding models from the digital twins to estimate failures or predict events. ➔ **Improve measurement availability at every level**
Operating Cycle	
• At the time of periodic maintenance, which is planned with a standard recurrent period worldwide. • In case of smoke or any other kind of visible contaminant occurring in the cabin, airlines must clean the entire cabin before being authorised to get the aircraft back into operation. This cleaning operation alone lasts 3 hours. Air quality recording and pollution control monitoring would help to limit the intervention to the strictly necessary cases and would ground less aircraft and, consequently increase aircraft availability.	• Specific physical measurements need to be performed by new devices to monitor the level of operation in real time and in flight and identify any leakage or defect in the fluid distribution. Data will also be used later to build explanatory models of aging. ➔ **Improved fluid quality & monitoring** ➔ **Improved fluid distribution systems compliance, reliability & operation** • Predictive and adaptive maintenance in accordance with the effective use, degradation and flight records are key enablers to: ➔ **Increase the global availability of aircraft**

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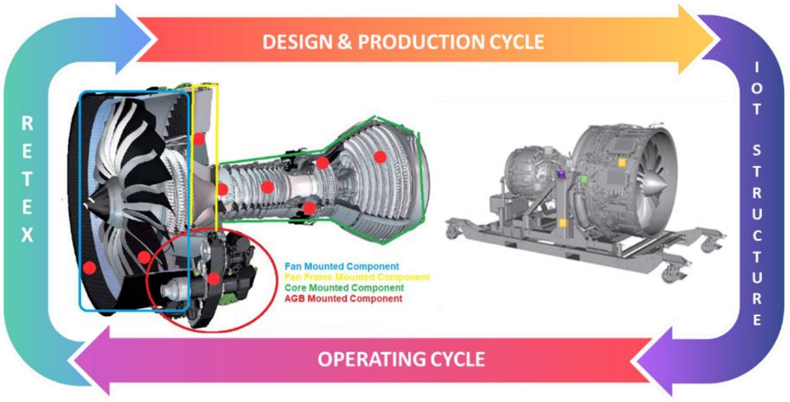
Use-case #6: Generic embedded sensor



Topics

Product Identification

Digital twins

Asset Tracking

Health Monitoring

IoT Interoperability

Context

Better knowledge of the structures or on-board equipment environment is a constantly sought for characteristic.

Collecting additional information to the data currently acquired by on-board health systems appears to be an essential function to:

- Improve knowledge of a parameter/behaviour of an aircraft component,
- Better understand the problems,
- Refine environment knowledge, to calibrate or update operational environment models,
- Prepare the introduction of post-development improvements with more accurate information.

Availability of plug and play sensors solutions along with a data platform can bring benefits at some stages of the lifecycle and we propose to illustrate and link them to the diagram.

Specification

We need a **pre-certified** sensor that shall **be smart, self-powered, embedding low or ultra-low power electronics, memory** and intelligent algorithms with or without wireless transceivers to monitor, store and transmit physical or environmental engine conditions to an engine health management system and which will contribute to performance along the lifecycle.

In this context, there is a need, in terms of sensors and removable systems capable of collecting and recording simultaneously and automatically in flight, over a given period, for key parameters such as: vibrations, pressure, temperature, etc.

The need is for wireless sensors, of the "Plug & Play" type and, if possible, flexible, which can:

- Stick to any surface,
- Easily collect environmental data,
- Send information to a “big data” server for further analysis,
- Complete a more independent fault diagnosis,
- Confirm/refine a previously issued diagnostic (algorithm, operator, pilot),
- Etc ...

These sensors must, in addition:

- Not, in any way, disturb the operations of the monitored system,
- Minimise crosstalk, between the different sensors, which influences their selective detection,
- Be autonomous in power supply,
- Have a good storage capacity,
- Communicate collected data, only during ground operations for certification reasons, via compact and highly efficient communication tools/channels and protocols, allowing smooth transmission of data between sensor nodes and IoT server,
- Survive the environment with accepted limits (occasional use, and limited life duration,
- Not be very bulky, with very low mass and low cost.

Steps	**Benefits**
Design & Production Cycle	
• Locate the equipment (trolley, turbomachine) during the logistical life phases (engine removed) and capture information to carry out health monitoring by including a geolocation component (GPS), a pressure, temperature, acceleration sensor and, if possible, moisture and particles.	• Asset Tracking of removable measuring. ➔ **Improve cost monitoring of maintenance equipment** ➔ **EFH contracts Optimisation** ➔ **Environmental data capture for HUMS (operations or logistics)**
IoT Structure	
• Measurement modular solution that can be assembled and dismantled in kit form.	• New devices of removable measuring. • New services of in-flight environmental data recording. ➔ **Improve knowledge of engine equipment or structures environments**
Operating Cycle	
• The plug and play sensors are connected to a "Big Data" server to which they provide their recorded information in either real or deferred time.	• The ability to monitor in flight additional information about parts environment will lead to refining the knowledge of their operating environment. ➔ **Improve components and structures design then reliability, safety** • Digital Twin shall integrate all the recorded data to obtain a better understanding of components behaviour associated with better modelling. • IoT Interoperability using existing IoT transmission channels. • Local storage in case of deferred time transmission. ➔ **Improve diagnostic** ➔ **Improve remaining useful life estimation** ➔ **Improve sensors installation** ➔ **Improve safety** ➔ **Improve maintenance operations**

Retex	
• The information recorded in flight and then analysed could lead to improving the specification and design of the engine components and structures, their manufacturing process by working on the weak points and reinforcing them. • This same information could statistically strengthen surveillance models and improve the definition of digital twins.	• Improve design, process and behaviour modelling. ➔ **Improve components and structures design and manufacturing process** ➔ **Improve components and structures survey model**

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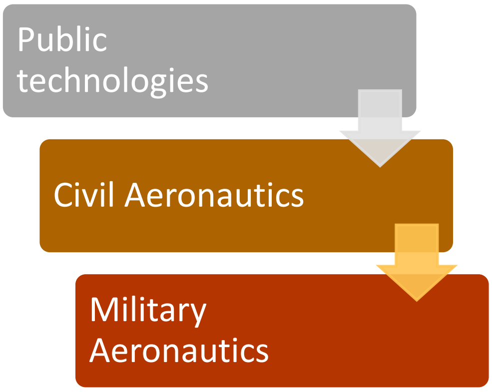
From civil IoT applications to defence solutions?

Defence and Space domains are constantly being innovated and improved to remain leaders of the systems in service.

Engineers are always looking for innovative technologies to integrate.

It recently appeared that the growing digitization of systems is leading to a new paradigm "The level of data available is now huge", increasing with technical innovations for the public technologies on sensors and connected devices.

IoT implementation levels



From the public technologies to civil aeronautics / from civil aeronautics to the military.

A first adoption is underway, in fact public technologies are starting to enter aeronautical systems such as civil aircraft (RFID, LIFI, etc.). This is a first stage of technical specification to reach aeronautical standards.

A second step is coming soon; these technologies can be chosen and then adapted to the integration of defence and space systems with a higher level of technical requirements.

Some key points, for example and illustration, allowing these technologies to enter defence systems

Environmental specifications	From the public technologies to aeronautics, a first step has been taken: reliability, service life, ... From civil aeronautics to defence environments, other requirements appear, such as reserved ranges of use, dedicated / chosen operators, dedicated networks, etc.
Data security / cybersecurity	The data exchanged between the systems and the environment is key and subject to specific requirements: encryption, authentication, right to know, certificate, impact analysis, etc. Consumer systems are also subject to these requirements, and technologies are improving daily. However, defence needs reach beyond public requirements and constantly evolve, meaning: systems of vital importance, defence clearance, means dedicated to this data processing, access control to these data, ...
Safety of the systems	We consider, in this part, the legal aspects and standards applicable to the defence systems that can include energetic materials, fuel, exhausts fumes, …
Data exchange	Data exchange is a vital point in the development of IoT technologies. Depending on the type and criticality of the data, technologies should be embedded to guarantee the integrity of the exchange and the confidentiality of the data during transmission. Stealth and resistance to communications jamming are essential.
Data governance	The technical, operational and organisational factors necessary for the MoD and armies to have high quality, robust, uncorrupted data. This governance brings together all the procedures, methods and technologies to be used throughout the data lifecycle. These include data quality, including data accuracy, integrity, accessibility, consistency, completeness, reliability and age. Consequently, the data lakes that gather all the information are part of a problematic that need to be covered separately or, as an example, the anonymisation could be carried out before transmission. Third-party services hosted on the internet will not be accessible on dedicated defence networks. These solutions could be embedded in the IoT Devices.

As a consequence:

In a Defence vision of IoT implementation, these technologies must bring new operational capabilities, lead to a substantial improvement of existing solutions or modify the use procedures or concepts in order to provide an advantage compared to other Forces.

A clear distinction will be established between the technologies deployed in a normal environment (unprotected requirements) in peacetime and secured national sites than more demanding operational usages (classified requirements).

The above requirements give some information on the technical requirements levels to reach according to the different use-cases. Clearly, support activities, training … and others will be first to benefit from these technologies.

These levels are often already part of the initial design of IoT devices and do not constitute a constraint in deployment possibilities but a chance for further business opportunities.

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Conclusion

The above described **IoT technologies** can and will be embedded in most of the aeronautic systems, from early design of airborne equipment to that of ground support, in view to ease and **to keep a full knowledge of the use parameters** and to tune, as closely as possible, the required support operations.

The **environmental conditions** will drive the technology choice in conjunction with the **safety and security requirements**, and particularly for sensitive equipment and defence systems with **cyber-security** constraints.

Today's challenges are less in data acquisition technologies, than the capability to render these **sensors energetically autonomous**, capable of storing a large amount of data and distributing these data quickly and efficiently.

A new type of challenge is to **allow pre-processing of the collected data** to allow the key information to be transmitted when necessary. Although **embedded A.I. technology** will, in the near future, ease this task.

Data broadcasting technology standards will require a worldwide compatibility allowing fleet management around the world.

Digital continuity is a key factor allowing precise equipment life management.

Embedded IoT technologies can ease work to carry out this mission.

IoT for Aeronautics is becoming a reality, you're welcome to a new world of business perspectives. Join us to share your needs, expose your solutions and attend our events.

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