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Embedded Life-Cycle Management
for Smart Multimaterials Structures:
Application to Engine Components

SHM Value for Aeronautics in an Evolving Environment

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SHM
-
Challenges & Constraints

Main Challenges of SHM in Aeronautics

Aerospace industry main challenges

- ❑ Limited fuel consumption
- ❑ Good power over mass ratio
  - Weight of $(\boldsymbol{New\ part} + \boldsymbol{SHM\ system} + \boldsymbol{Installation}) \leq$ Weight of Former Part
- ❑ Risk of a new technology (vs maturity & certification)
- ❑ SHM not only for diagnostic
  - Also for life extension due to its integration
  - No impact on the MTBUR (Mean Time Before Unscheduled Removal)

Constraints

Size

- The dimensions of the SHM system should fit to the available amount of space and the structural integrity of the equipment should not suffer of its integration

Weight

- An additional weight will impact fuel consumption and payload capacity

Power

- The power consumption of the SHM system should be adapted to the available power on the aircraft

Cost

- The impact of physical dimensions of the SHM system should be evaluated
- The cost-benefit analysis of an SHM system must consider the additional weight it may add to an aircraft

SHM Main concerns

❑ The new equipment (including SHM system) compared to the former one

- Must be at least as reliable as the former equipment, which is already reliable
- Should be able to assess damage and manage usage
- Should not weight more
- Should not consume too much
- Should have approximatively the same or lower cost

New Paradigm

New expectations

- **Not only Health Monitoring**
- **Also Health Management (damage, fatigue, load, …)**
- **Damage assessment gains benefits from new technologies**
  - Additive manufacturing, surface functionalization → embedding SHM and sensors network
  - IIOT (Industrial Internet of Things) → collaborative networks
  - Augmented reality for HMI → collaboration between human and machines
  - AI (Artificial Intelligence)/Model based → data analysis and prognostic
- **and moving to**
  - Damage awareness
  - Prognostic → RUL (Remaining Useful Life)
  - Damage Tolerant Equipment

Global system

- ❑ **OEMs → n * SHM**
- ❑ **Aircraft → SHM**
- ❑ **Airline → multiple SHM systems**
- ❑ **Concerns**
  - Interoperability
  - Global system optimization: size, weight, cost, power consumption
  - Decision making
- ❑ **Data**
  - Ownership
  - Services
  - Responsibility

→

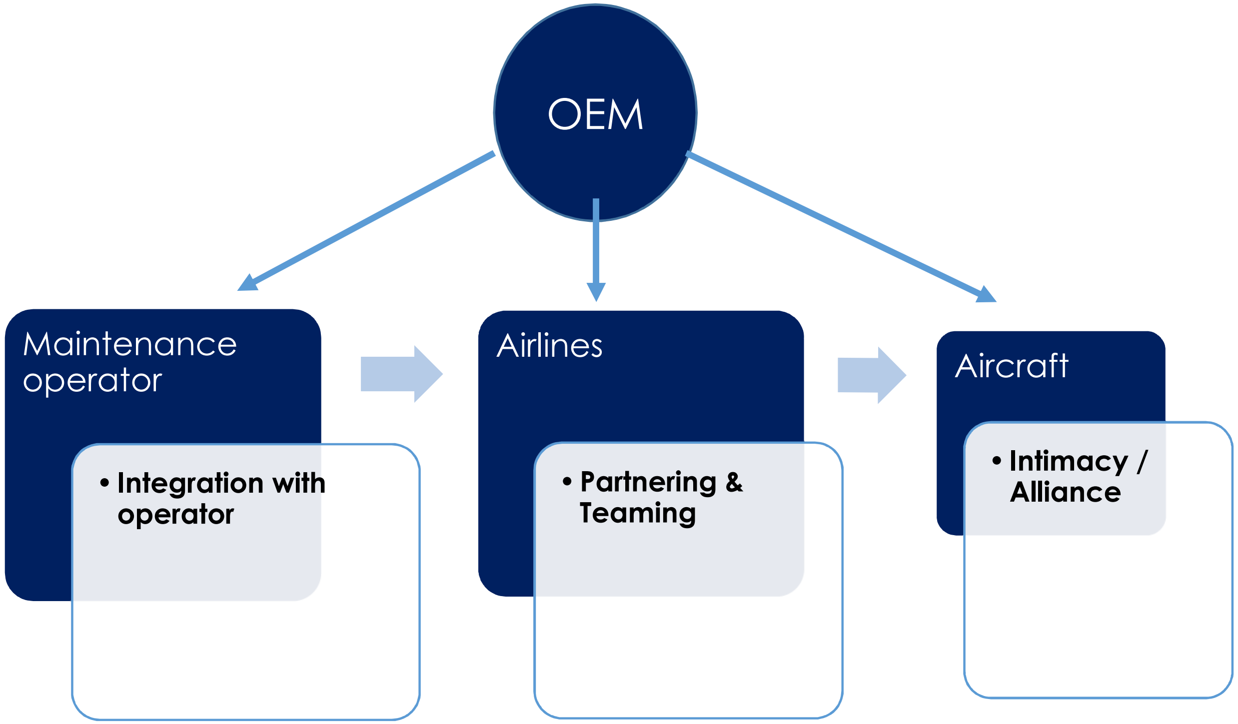
Need of global system approach

Interest for collaborative work of stakeholders

SHM & Global system

❑ Interest of collaborative approach between stakeholders

- Constraints allocation
- Components sharing
- Data / useful information sharing



From Health Monitoring to Health Management

SHM: Structural Health Monitoring/Management

SHM: System Health Management → ISHM: Integrated System Health Management

IVHM: Integrated Vehicle Health Management

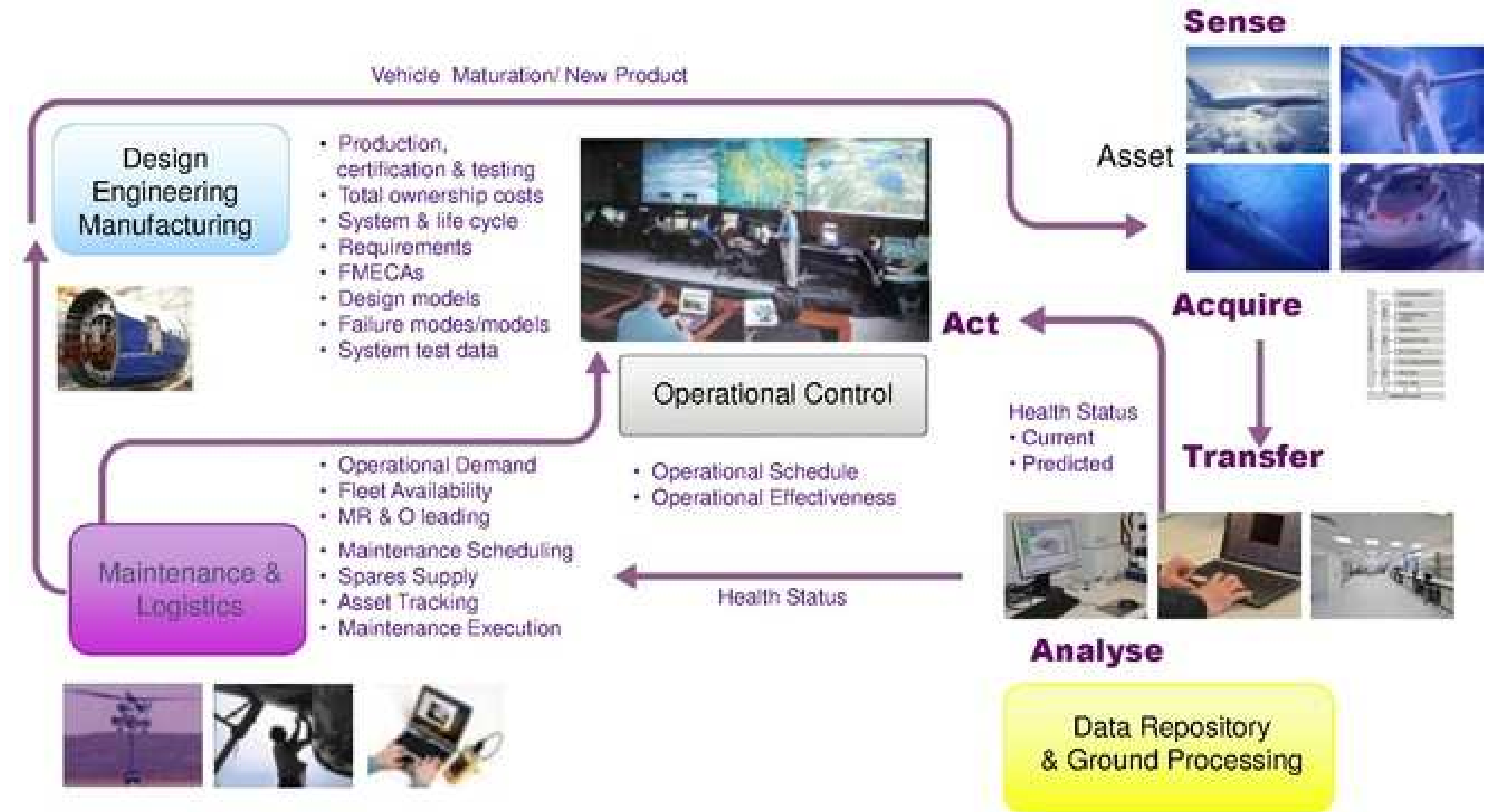
Integrated system (vehicle) health management (**ISHM or IVHM**) is the unified capability of systems to assess the current or future state of the member system health and integrate that picture of system health within a framework of available resources and operational demand

The aims of ISHM are to enable better management of vehicle and vehicle fleet health.

- ❖ **Improve safety** through use of **diagnostics and prognostics** to fix faults before they are an issue.
- ❖ **Improve availability** through better maintenance scheduling
- ❖ **Improve reliability** through a more thorough **understanding of the current health of the system** and **prognosis based maintenance**
- ❖ **Reduce total cost of maintenance** through reduction of unnecessary maintenance and avoidance of unscheduled maintenance

Source: https://en.wikipedia.org/wiki/Integrated_vehicle_health_management

Larger View of ISHM



IVHM concept as described by Professor Ian Jennions et al.
of the IVHM Centre, Cranfield University.

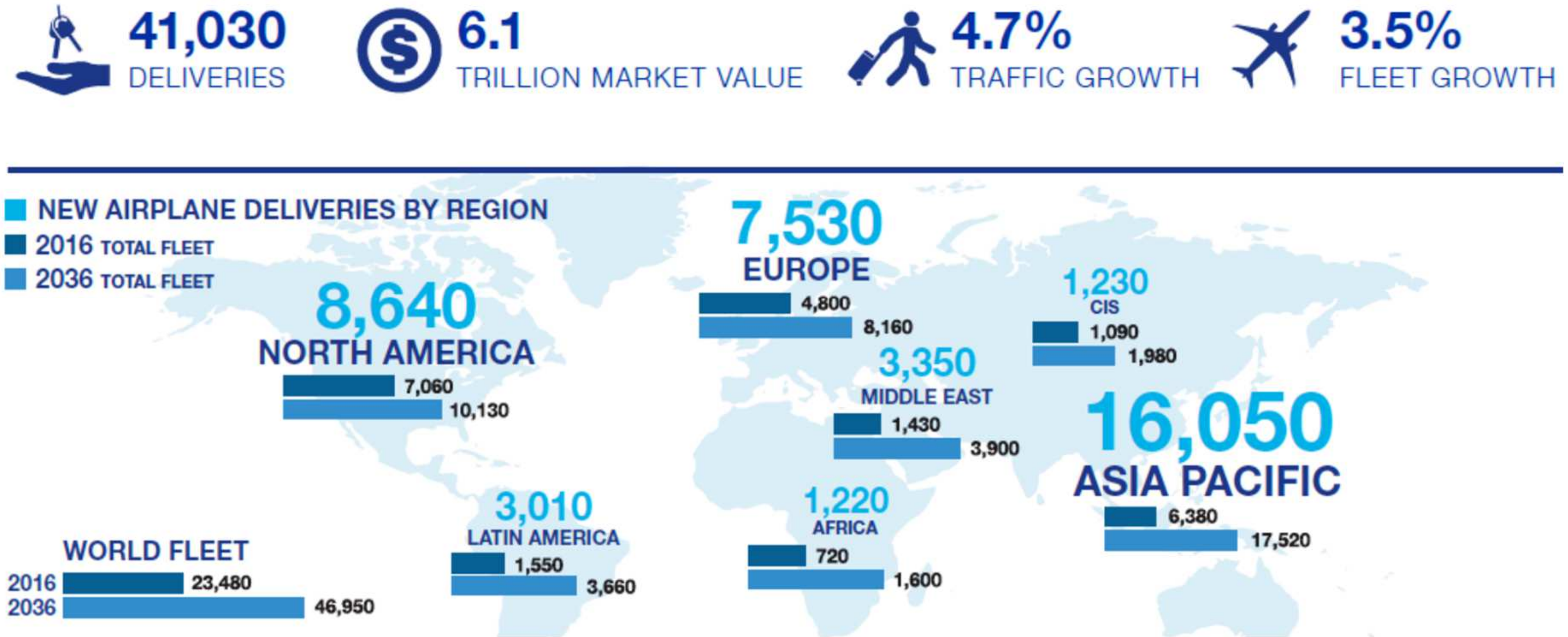
Potential Added Value

Voice of Customer (VOC)

Customers

- ❑ Reduction of Operational Interrupt for airlines (~90%)
- ❑ Life cost reduction for the whole air traffic
- ❑ Travellers safety
- ❑ Greener traffic for public opinion

Aviation Market Forecast 2017 → 2036



Source: Boeing/Airbus/Bombardier

MROs and airliners competitiveness

- In 2016, around 28,000 commercial aircraft carry an estimated 3.5 billion passengers around the world. This number was expected to double by 2026, to a total of 40,000 aircraft carrying 7 billion passengers. Then …. COVID-19
  - But it will happen, not in 2026 perhaps 2030?!
- To guarantee the safety and airworthiness of these aircrafts, Maintenance, Repair and Overhaul (MRO) is a necessity.
- The estimated value of the global aircraft MRO market is $67.6 billion (and growing). Responsible for 35%–40% of an airline's maintenance cost, engine MRO is dominating the market.
- While an engine average turnaround time (TaT) is estimated to be 60 days with up to 50% of additional deviation.
  - One an aircraft reaches the gate, the ground support has to get the aircraft checked, cleaned, refueled, unloaded and reloaded, and ready for its next flight
  - This deviation mainly depends on the diagnostic stage duration. Providing at early stage and automated health assessment and prognostic, will highly contribute to reduce the TaT and its deviation
- Direct impact on competitiveness of MRO companies and reduction maintenance down time. This have a direct impact on the airliners operation costs.

*Source: C. Doan / 2015-2025 GLOBAL FLEET & MRO MARKET FORECAST

SHM & OEM Market

- **OEM.s increased aftermarket presence**
  - Increased aftermarket market share for the newest generation of aircraft
- **New repair capabilities required**
  - Decisions necessary enter new markets for each of airframe, engine and component repairs
- **Less maintenance**
  - Health monitoring and predictive maintenance will reduce overall time-on-tool requirements for individual checks with fewer repairs
- **Increased use of data analytics**
  - Critical new source of value to the aftermarket driven by those who design the best algorithms and most rigorous data management

Potential values

- **MRO ↠ Significant reduction of maintenance costs and increase of aircraft availability**
  - Develop probabilistic SHM-data-driven methodologies for damage assessment as well as the remaining useful life (RUL)
  - Qualify the use of embedded sensors for the assessment of life cycle of components/systems
  - Enable a new inspection strategy of components/systems based on automated SHM technology.
- **Ecology and recycling ↠ Partial or total recovering of materials**
  - Develop a new methodology to optimize disassembling and recycling of components after their end of service life.
- **Qualification/Standards/Certification ↠ Adoption of standards for Embedded Life Cycle Management**
  - Propose guidelines and standards for the certification and implementation of the innovative manufacturing process.
  - Propose guidelines and standards in the implementation of SHM system

Concluding Remarks

MRO to Support, Maintenance and Services

- **Ensure and maintain operational excellence for our customers**
  - Increase the capacity for maintenance forecast and schedule
  - Develop efficient means for assistance (trouble shooting, inspection…)
  - Provide more efficient maintenance operations (TAT reduction, repairs, logistic, etc…)

- **Bring maintenance requirements to design level for new equipments and systems**
  - Learn from experience in operations
  - Include support & maintenance system requirements

- **Support equipments and systems performances in operations (environment, airworthiness)**
  - Maintain or increase same level of performance
  - Reduce environmental footprint of maintenance operations (replacement vs repair, new processes…)
  - Recycle parts

- **Increase maintenance and associated services revenues and margins**
  - Develop new service offers
  - Improve competitiveness of maintenance, shop repairs
  - Improve spare forecast

A main leverage: digital transformation

- Cyber-physical system (CPS): for collaboration between computational entities and the surrounding sensors technologies that allow generating data in real time

There's room for innovation

- Innovative joining technologies and **damage diagnostics for** aircraft equipments and systems, with high potential to offer substantial benefits towards reduced weight, while allowing for **faster and leaner integration and repair**
- **Advanced quality monitoring and on-line process control**, applied to flexible automation of manufacturing, maintenance, repair processes to increase rates.
- **Manufacturing processes for the production of multifunctional and smart parts & systems**, covering the whole production chain with a view to support activities such as **supervision**
- **Integrated technologies and methodologies towards next generation health management and monitoring**, together with sensor development, wireless networks and data-driven fault detection
- **New MRO and recycling technologies** for Multifunctional and Smart parts and systems
- **Tackle standardisation,** development of best-practice guidelines and processes for the certification of airframe and engine components and assemblies, with particular emphasis on simulation-assisted certification issues.

Evolution of ISHM concepts

❑ IHMM (Intelligent Health & Mission Management)

- "The benefits of ISHM include enhancing the maintainability, reliability, safety and performance of systems. The next evolution of the ISHM concept, Intelligent Health and Mission Management (IHMM), delves deeper into the utilization of on-line system health predictions to modify mission profiles to ensure safety and reliability, as well as efficiency through predictive integrity"

SHM	Structural Health Monitoring	1960
VHM	Vehicle Health Monitoring	1970
IVHM	Integrated Vehicle Health Management	1980
ISHM	Integrated System Health Monitoring	1990
PHM	Prognostics and Health Management	2000
ISHM	Integrated System Health Management	2020 +
IHMM	Intelligent Health and Mission Management	

Source: Advances in Integrated System Health Management for mission-essential and safety-critical aerospace applications, K. Ranasinghe et al., Progress in Aerospace Sciences - Volume 128, 1 January 2022, 100758

C2 - Confidential

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