

Requirements for RFID-based Sensor Integration in Landing Gear Monitoring – A Case Study

Béla Pátkai, Lila Theodorou, Duncan McFarlane, Kyle Schmidt*

Auto-ID Lab, University of Cambridge, UK

****Messier-Dowty Inc., Canada***

Report Abstract: This case study aims at analysing the requirements for the integration of RFID and sensors in the integrated system health management process of aircraft landing gears. The study is based on a number of interviews and site visits at Messier-Dowty and Messier Services as well as on previous research conducted at the Cambridge Auto-ID Lab. The discussion, vision and the conclusions all aim at presenting the gathered requirements and the establishments for system design at a general level, hence the information about specific sensors and data requirements should be regarded as illustrative, realistic examples, not as an actual design specification.

Contents

1.	Introduction	3
1.1.	Overview	3
1.2.	Aims of the case study	3
1.3.	Case study approach	4
1.4.	Report structure	4
2.	Integrated System Health Management	5
3.	ID-based Sensor Integration	10
4.	Landing Gear Health Management	13
4.1.	Overview	13
5.	Requirements Analysis	18
5.1.	Unique identification	18
5.2.	Sensor data	18
5.3.	Systems and networking	22
5.3.1.	Data storage requirements	22
5.3.2.	Sensor data processing	22
5.3.3.	Data retrieval	22
5.3.4.	Data communication	23
5.3.5.	Power management	23
5.3.6.	System scalability	23
5.3.7.	System durability	23
5.3.8.	Security issues	23
5.4.	Environmental constraints	24
5.5.	Criteria for solution selection	25
6.	Conclusions	27
7.	Acknowledgements	27
8.	References	27

1. Introduction

1.1. Overview

The *Aerospace ID* technologies programme at the Cambridge Auto-ID Lab addresses several research topics related to Radiofrequency Identification (RFID). These topics are concerned with the selection of unique identification (ID) technology, management of identity and lifecycle data throughout product lifecycle, tracking and tracing, synchronization of data between tags and online databases, and finally *the integration of sensors with RFID* ([1], [2], [3]), the subject of this case study.

The integration of closely related technologies like RFID and sensors is technologically possible, but the feasibility and convenience of the integration has to be verified in terms of application and its economic viability.

The aerospace industry has many special requirements for new technologies due to the long lifecycle of aircraft parts, importance of seat availability, high costs and numerous safety regulations. These provide a high motivation for improvements in many areas. System *health* – or *condition* – monitoring and management is typically an area that can improve safety, seat availability, aircraft turn-around time and provide additional cost benefits for the aerospace industry.

1.2. Aims of the case study

The general aim of this case study is to analyse the requirements and potential of ID-based sensor integration in a realistic application domain. Messier-Dowty (M-D) are an ideal contributor to this report because they design and develop landing gear systems for a diverse range of aircrafts and are suppliers of numerous aircraft manufacturers, such as Boeing and Airbus. Also, they are collaborating with and partially owning Messier Services (M-S) that provide maintenance and overhaul for all the landing gears developed by M-D. Building on the combined expertise and research interests of the authors of this report, the specific aims of this case study are:

Use landing gear health monitoring as an illustrative example with general applicability to other application domains for RFID-based sensor integration.

Analyse the processes and decisions related to landing gear monitoring.

- Analyse the requirements for combining the identity of a part with sensor data from.

- Estimate the potential of RFID-based sensor integration in this field.
- Contribute to the general requirements for this technology.

1.3. Case study approach

Based on the aims of this case study the landing gear monitoring, maintenance and overhaul process was analysed first with the help of M-D and M-S. Several preliminary phone and personal interviews were conducted and questionnaires developed to improve understanding of potential requirements for integrated system health management. These interviews established a common understanding of research challenges, after which the integration of RFID and sensors was analysed as a potential technology for solving many current and future problems expected in solution development and deployment.

Even though landing gears' health management was used during the case study project discussions and interviews, the generality of the problem was always kept in mind and emphasized in order to allow a general audience to benefit from this study.

1.4. Report structure

The report structure loosely follows the structure of the case study project, as it is depicted in Figure 1.1.

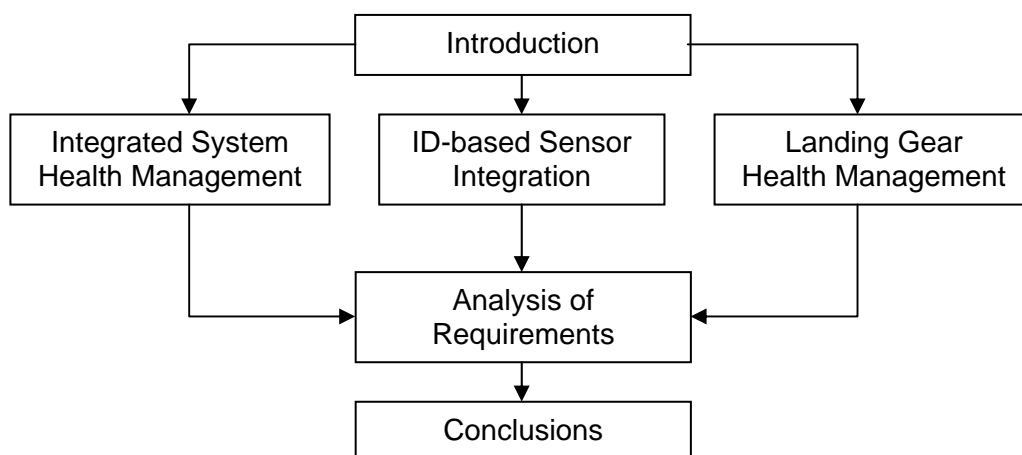


Figure 1.1: Report structure

2. Integrated System Health Management

2.1. Motivation and definitions

Research and development in the area of Integrated System Health Management (ISHM) consists of a diverse set of applications, technology solutions and integrated services. It is a rapidly emerging area of research, motivated by timely challenges in aerospace as illustrated in Figure 2.1.

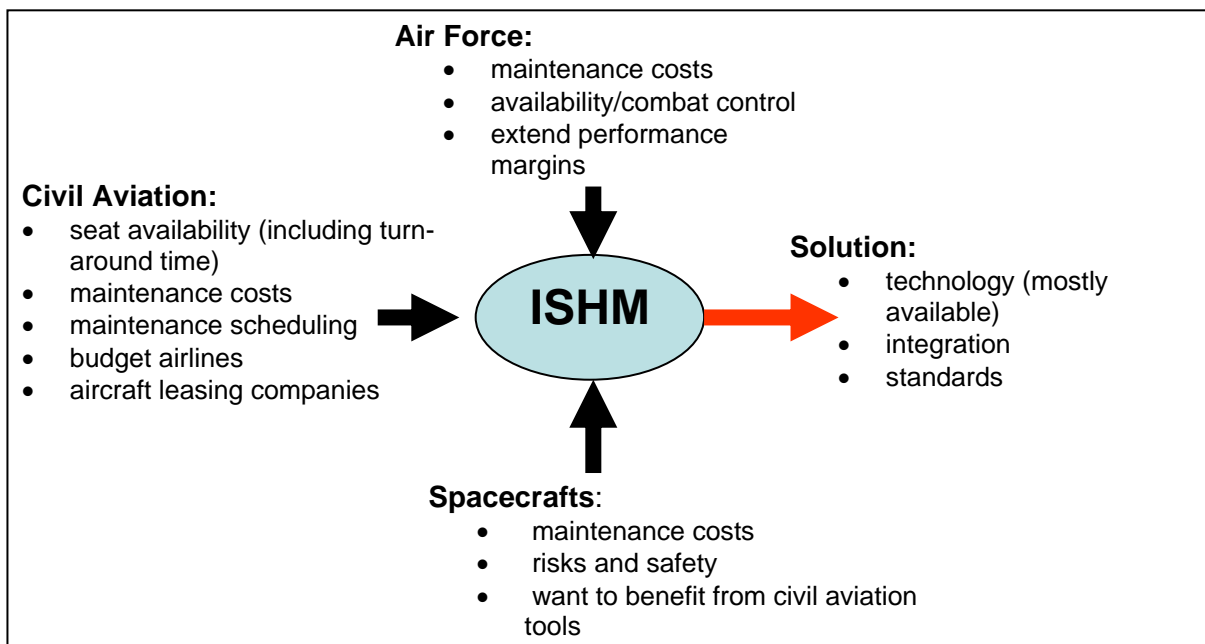


Figure 2.1: Motivation for ISHM in aerospace

The diversity of the field is manifested in several, largely overlapping areas of activity, represented by the following definitions:

- DoD policy states that Condition Based Maintenance (CBM) is [8]:
“...implemented to improve maintenance agility and responsiveness, increase operational availability, and reduce lifecycle total ownership costs.”
- Integrated Condition Management (ICM) is often defined as:

“... a system that uses real-time data to prioritize and optimize maintenance resources. That system will determine the equipment's health, and act only when maintenance is actually necessary.”

- ICM largely overlaps with:
 - AHM – Aircraft Health Management (Boeing terminology)
 - AHMM – Advanced Health Monitoring and Management (Airbus terminology)
 - ISHM – Integrated System Health Management (NASA/JPL terminology)
 - IVHM – Integrated Vehicle Health Management (TATEM EU project terminology)

The definition of CBM suggests more focus on the actual observation and maintenance tasks, while the rest of the definitions aim at an integrated view of systems. The specific steps of such monitoring and health management processes can be broken down to the following steps:

- Health *monitoring*
 - Data acquisition (logging)
 - Signal processing (including signal conditioning)
 - Detection
- Health *management*
 - Assessment
 - Prognosis
 - Decision support
 - Presentation to end users

None of the currently available standards address all these steps.

2.2. Standards

The complexity of ISHM systems and the necessity for collaboration between a number of parties with varying amount of interest motivates the development of standards. Currently the “Operations and Maintenance Information Open Systems Alliance” (MIMOSA) Open System Architecture for Condition-Based Maintenance (OSA-CBM) candidate standard is the closest to satisfying aerospace requirements and enjoys growing support [9]. Its long-term objective is ISO standardization.

Figure 2.2 and Figure 2.3 show the OSA-CBM standards' origins and features, such as:

- Layered architecture
- Information specification
 - Defining data types used for processing and results reporting in a condition monitoring system
- Interface specification
 - Defining how that information moves between process and storage points
- Multi-technology basis
 - Abstract UML mapping to:
 - Programming languages
 - Inter-process communication
- Built-in data storage capability

It is reasonable to expect that either this standard or one with a similar structure is going to play a role in the integration efforts of the aerospace community in the area of ISHM.

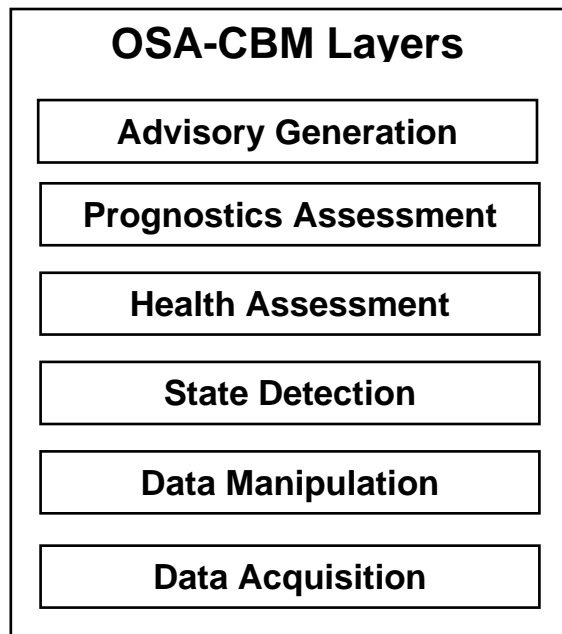


Figure 2.2: OSA-CBM Layers (based on [9])

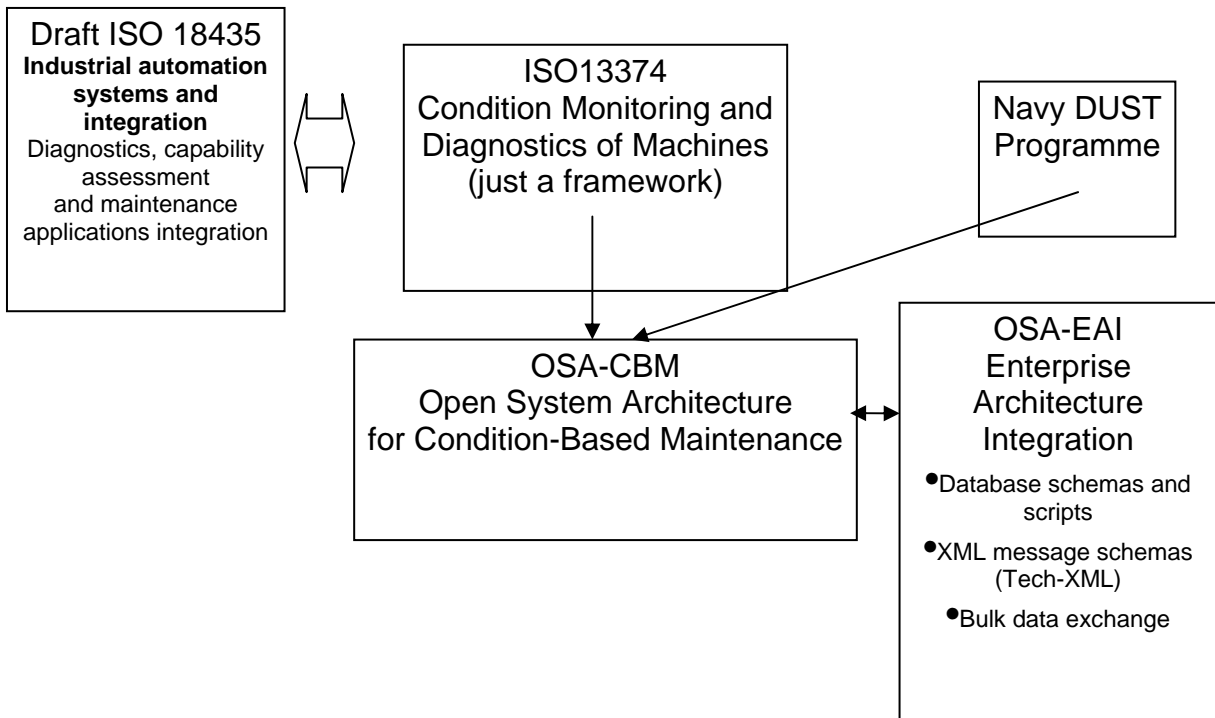


Figure 2.3: Origins of the MIMOSA/Open O&M Set of Standards (based on [9])

2.3. Challenges

The ISHM community has to face a number of challenges when it proceeds with integration, standardization and novel application development efforts. Some of these challenges are as follows.

- Technology and building blocks are available but unutilized and disintegrated.
- Subsystem monitoring is usually done but integration is missing at nearly all levels.
- End users are drowning in data but there is lack information.
- Integration is motivated from bottom-up and done step-by-step, promoting evolutionary changes even when revolutionary or disruptive changes would be necessary.

- Integration of legacy systems is painstaking, expensive and may provide insufficient benefits.
- Lack of standards or their application (for example, far too many data buses used even inside a single company).
- Platform preservation and mission execution.
- Untested performance characteristics.

3. ID-based Sensor Integration

As the terms 'sensor fusion', 'RFID-based sensor integration' and 'networked RFID' are used often in this document a definition and a short description is provided in this section.

Using a combination of sensors instead of just one and making more informed decisions on that basis is called *sensor fusion*. A more formal definition is given in [6]:

“Sensor fusion is concerned with the combination of how to combine data from multiple (and possibly diverse) sensors in order to make inferences about a physical event, activity, or situation.”

The research community has referred to the same principle with different names, for example 'multi-sensor data fusion' and 'data fusion', but 'sensor fusion' is the most commonly accepted one. Information fusion expands this view and provides a broader field of research as it is reflected in the definition given in [7]:

“Information fusion encompasses theory, techniques and tools conceived and employed for exploiting the synergy in the information acquired from multiple sources (sensor, databases, information gathered by human, etc.) such that the resulting decision or action is in some sense better (qualitatively or quantitatively, in terms of accuracy, robustness, etc.) than would be possible if any of these sources were used individually without such synergy exploitation.”

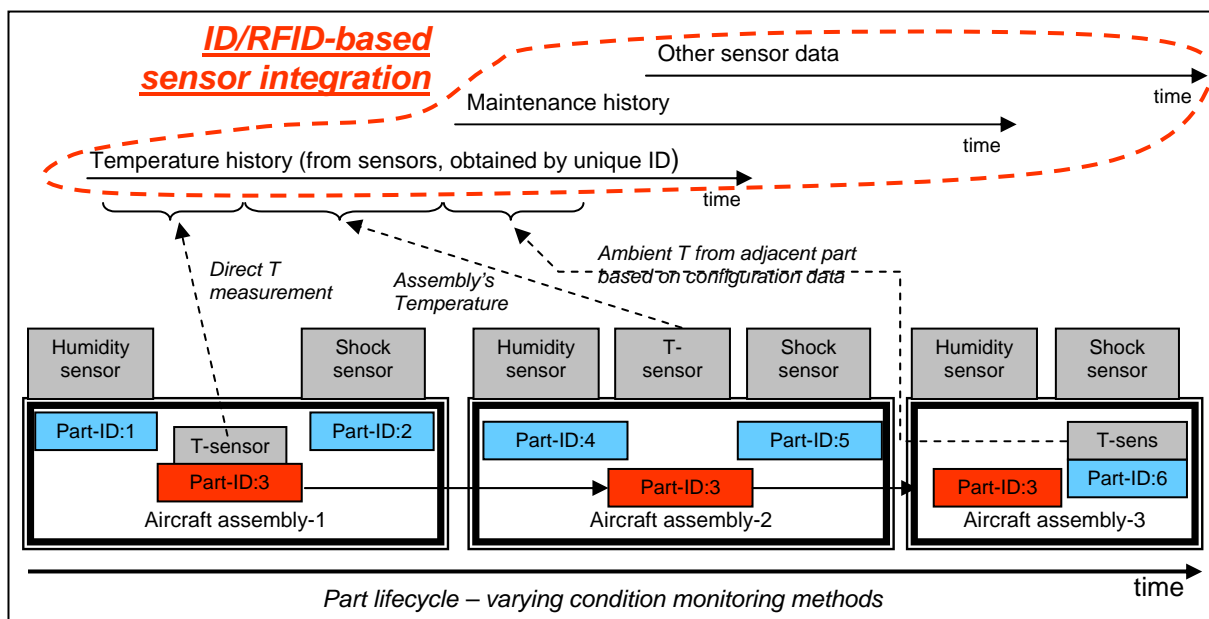


Figure 3.1: The concept of ID-based sensor integration

'RFID-based' sensor integration means that RFID tags – passive or active – are added to the sensor fusion scenario. In this case, not just the state of a particular object but also its unique identity is known – providing access to all the information associated with it throughout its lifecycle.

In Figure 3.1 the concept of ID-based sensor integration is presented. More specifically, we aim to depict that an aircraft part, such as part-ID:3 in this case, is likely to be used in different aircraft assemblies during its lifecycle. Moreover, it is quite possible that sensing parameters affecting part's condition (temperature in this case) might be monitored in different ways in each assembly. For instance, in the first assembly, the temperature sensor is on-board the part taking direct measurements, in the second assembly, the sensor is taking ambient measurements and in the third assembly, the sensor is mounted on-board another part that is closely located to part-ID:3. ID-based integration requires the fusion of ID data and sensor data generated during the time periods the part was used in all the three aircraft assemblies.

The integration of RFID and sensors can be done in at least two distinct ways:

Hardware integration: The sensor(s) is connected physically to the RFID tag, and sensor data is read by the – wireless – RFID reader.

Logical integration: Sensor data is collected independent of the RFID tag and the integration process involves the reading of the RFID tag and accessing another data source.

In case of hardware integration, sensor data is associated with the identity of the sensed object at the hardware level. Moreover, product ID and sensor data are transmitted synchronously through the same interface to the upper layers of the architecture. Hardware integration can be realised through the use of sensor tags mounted on the object whose condition needs to be estimated. In this case, sensor data generated by the on-board sensors clearly correspond to the condition of the tagged item. Another way of realising hardware integration is by transferring sensor data from external sensors in the memory of the RFID tag or an on-board product memory.

On the other hand, in case of logical integration, sensor data is collected independently of the product ID data (independent devices, transmitted through different channels and/or asynchronously). Sensor data can be derived from sensor devices, sensor nodes or from other data repositories and are associated with the product ID at the middleware layer, or data repository layer or the application layer.

ID sensor data integration can also be classified in terms of whether integration is done in advance or on demand after a query. We can distinguish between two approaches:

Approach 1: Materialized integration

Approach 2: Virtual integration

The materialized approach physically integrates all relevant data in advance in a central database, the so-called data warehouse, which promises significant advantages regarding

ease of use and performance, especially for queries involving large amounts of data. However, the data warehouse needs to be regularly updated with new data.

The virtual approach, also called mediator, identifies and queries the relevant sources, and assembles the results returned by the sources to a final result. Up-to-date data is obtained, however at the price of high effort at query time.

4. Landing Gear Health Management

4.1. Overview

Landing gears are currently identified at item level by using barcode technology, hence tracking and tracing landing gear parts requires the use of conventional data management tools and processes. RFID tagging of parts for the Boeing 787 aircraft is in progress. Passive, high-memory tags will be used and maintenance-related data will be stored on tag to simplify data access and improve identification of parts.

The application of sensors and a health management system is planned in the long term. Currently there is no sensor monitoring solution in place. Usage and performance data, such as number of landings, statistical data regarding altitude, speed, actual centre of gravity and descent rate are received from the operators only for incident analysis.

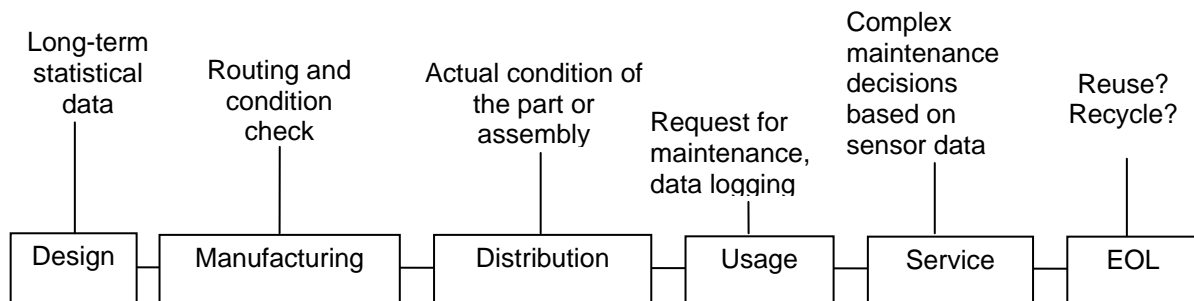


Figure 4.1: Typical lifecycle of aircraft parts with data requirements

The deployment of RFID and sensors will provide enhanced information about the condition and usage of landing gear parts throughout their lifecycle, during which they are often exchanged from one landing gear to another. This information is expected to significantly benefit maintenance, repair and redesign operations. However, it is the aim of this case study to emphasize that sensors and RFID are not two separate solutions, but their effective combination provides new possibilities for advanced health management.

Figure 4.1 shows the typical lifecycle of aircraft parts. The next sections provide a summary of landing gear design, usage, maintenance and repair problems, as these are the most important decision points of their lifecycle from the point of view of ISHM and RFID-based sensor integration.

4.2. Design and redesign

Messier-Dowty designs and develops landing gear systems for a diverse range of aircraft. It supplies to numerous aircraft manufacturers, such as Boeing and Airbus. As designers and manufacturers, they need lifecycle data for improving their designs and hence require close contact with maintenance, repair and overhaul (MRO) to be able to improve their support for MRO activities.

Designers receive some data from the operators, such as number of landings, notification about incidents as well as statistical data relevant to the aircraft operation, for example aircraft altitude, speed, centre of gravity position and descent rate. The above data provide indirect information about the condition of the landing gear parts, which can be used to build analytical or simulation models.

Design and especially design modifications in the redesign phase of product development already benefits from data obtained from the landing gears. It is the common understanding of M-D that obtaining sensor data from the landing gears would open up many possibilities for improving design and maintenance quality. These expected benefits are summarized in the last section of this chapter.

4.3. Usage

Due to the long lifecycle of landing gears, any observations and predictions on part lifetime have a long time span. Safety regulations and certification will not allow the designing of unreliable parts with possible failure, so diagnostics is not required for indicating imminent failure possibilities. Data collection and prognostics is more likely to happen off-line by ground services, operators, MRO's or certifying authorities to provide parallel proof of any new prognostic methods. Hence the presentation of sensor and/or RFID-based information to the crew is mainly useful to indicate hard landings and will contribute to the automation of incident reporting and analysis.

4.4. Maintenance, repair and overhaul

M-S provides maintenance and overhaul for all types of landing gears developed by M-D. Depending on the type of contract with the operators, maintenance operations are usually carried out at regular intervals defined by the number of landings the undercarriages have performed.

Major repair operations are conducted in case of serious incidents reported by the operators. Reported types of incidents are 'heavy landings' and 'collisions'. Minor repairs and maintenance are carried out on-wing by the operators themselves, while major overhaul and more serious maintenance operations have to be done at M-S maintenance sites.

M-D provides M-S — and any other maintenance providers — with instructions on how to carry out repair based on the data received from the operators (number of landings and aircraft operational data). Instructions on repair, overhaul and maintenance operations are all included in the maintenance and repair handbook of landing gear systems. Once landing gears are received in M-S facilities for repair or overhaul, they are disassembled to parts and tested for different types of failure modes. Depending on the test results, parts can be repaired, replaced or scrapped and sent for recycle.

Landing gears are then reassembled and sent back to the operators. M-D equips landing gears with a shock absorber. The absorber has energy absorption characteristics determined by the quantities of gas and oil within it. It is very common that operators compensate oil levels by filling in gas instead of oil, because it is a simpler and cleaner process. Consequently, the shock absorbers' characteristics change and the landing gear may be more easily damaged, and thus the usage data has to reflect the changed operational conditions.

Landing gear parts are very reliable and, as a result, they are very unlikely to fail, with the exception of hydraulic parts, which are somewhat less critical to safety. It is very unlikely that cracks evolve in case of the used high quality and high strength materials. However, if they do evolve then they do it slowly, but failure happens abruptly. Corrosion is usually caused by high levels of humidity and its coexistence with stress ('stress corrosion'). Large differences between air and part temperature cause part 'sweating', i.e. the condensation of water vapour in air.

Nose gears are much more sensitive to stress than main gears due to their position and lighter design. Collisions are also more likely to happen at the front of the aircraft, hence monitoring systems have an elevated importance in case of nose gears.

There are some methods to estimate the remaining life of components based on their target life and the cumulative life consumed, which in turn is defined by the number of landings and maintenance events during their lifecycle as well the type of repair carried out on them.

4.5. Summary of challenges

Summarizing, the following challenges were identified for ISHM:

- Limited amount of data is received from operators.
- Quality of part maintenance is nearly unknown (parts may be used out of specification for a while).
- Data gathering is not automated; data is not stored centrally and cannot be easily queried if it involves more than one source.
- Parts are not identified automatically. (As they are often exchanged from one landing gear to another, it is challenging to trace the lifecycle of parts.)
- Incident reporting and analysis is not automated.
- Due to the lack of information (sensor data) from parts, prognostics methods cannot be refined.
- Any new prognostics methods, based on the availability of new sensor data, need to be developed, tested, proved and approved.
- Data sharing, authentication, authorization and access control.

4.6. Vision for ISHM

Many of the previously listed challenges will be addressed by a new ISHM system that will eventually be developed at M-D for landing gear monitoring. According to M-S, the deployment of RFID and sensors, which will monitor the condition of landing gear parts, will provide them with more enhanced information, which can possibly enable:

- Predictive maintenance in place of preventative maintenance
- Optimised stock levels of spares
- Minimization of scrap
- Elimination of bottlenecks in machine usage during overhaul/maintenance operations
- Reduction in turnaround time (by providing readily available information)
- Utilizing enhanced information as a marketing tool, 'selling landing gear performance'
- Evaluation of in-service performance
- Optimization of design efficiency by bringing extensive knowledge of in-service performance to the development effort. More specifically, market needs will be met and the serviceability of the gears will be optimised
- Availability of data about the condition of the landing gear, which will enable M-D to ensure that parts are operating within the design specifications

- In case of an incident, such as a hard landing, sensor data will provide a direct and more refined indication (instead of a mere “yes/no hard landing”) about the seriousness of the situation and the appropriate repair operations will be scheduled

It is expected that the deployment of RFID and sensors will provide enhanced information about the condition and usage of landing gear parts throughout their lifecycle, which can be utilized in numerous ways currently unforeseen.

5. Requirements Analysis

We have identified five categories of requirements in the context of a specific RFID-based sensor integration application. These are:

- unique identification;
- sensor data and sensor selection;
- system requirements; and
- environmental requirements/restrictions.

The following sections elaborate more on these categories of requirements.

5.1. Unique identification

The landing gear health monitoring system should provide the condition of landing gears at component level. More specifically, each component needs to be associated with its damage state, as well as its usage and maintenance history. Given the fact that components are often replaced from one landing gear to another, the unique identification of landing gear components, at least at the LRU level, is required. Unique component identification requires each part to be associated with a part number and a serial number that will be stored on-board the landing gear components. In this way, part-specific information tracking and tracing will be enabled.

5.2. Sensor data

5.2.1. General requirements

This category of requirements refers to the type and the characteristics of the data needed for product state assessment and hence for the related decision-making processes.

Three types of data are required for estimating the condition of the landing gear: ID data, sensor data as well as other types of data, which will be next analysed.

- Identification (ID) data are required for all Line Replaceable Units (LRUs) – this is covered in the previous section.

- Critical sensing parameters that can affect the condition of parts and thus need to be monitored are the following:
 - Shock
 - Strain
 - Acceleration
 - Stress (pressure)
 - Load
 - Humidity
 - Brakes' temperature: The temperature of the brakes can easily increase, overcoming the prescribed limits. Brakes are located closely to the landing gears, affecting their condition in case of a significant temperature increase. More specifically, the protective coating of the landing gear may melt due to excessive temperature.
 - Leakage of oil from hydraulic parts
 - Gas and oil level indicators, as well as other parameters that may affect the quality of the shock absorber

Some more general requirements for sensor data:

- Sensor data should provide direct and not inferred information about the condition of the part. For that purpose, they should be located on the parts themselves and not embedded in the infrastructure (with the exception of the temperature sensor for the brakes).
- The level of accuracy, precision and timeliness required will differ from sensing parameter to parameter. For instance, accelerometer data should be accurate and rapidly transmitted, whereas there is little need for high rate pressure data.

Other data required for assessing the state and condition of landing gears are the following:

- Number of landings
- Finite life of components
- Detailed recording of maintenance and repair events
- Aircraft operational data

5.2.2. Sensor selection

We first present the main sensing parameters that need to be measured in order to assess the condition of landing gear components. ISHM is required to provide the fatigue damage state of landing gear components. High strength materials used in the design of landing gears are characterized by very rapid crack growth following crack initiation. As a result, potential fatigue damage needs to be detected before crack initiation. For that purpose, **load**, **pressure** and **shock** measurements need to be taken. The detection of overload events would also be of great importance.

Moreover, high-strength steels are also prone to corrosion and wear due to the usage of many dissimilar materials. Corrosion can also be caused by excessive humidity conditions due to part 'sweating' or leakage and is very difficult to be detected in critical areas. As a result, **humidity** measurements need to be taken for corrosion detection.

Landing gears are equipped with a shock absorber in order to be protected from the significant amounts of shock received during incidents, such as hard landings. Their reliability depends on maintaining the specified oil and gas levels in the absorber. Given the fact that liquid level sensor technology is not flawless, **pressure**, **volume**, **temperature** and **position (linear and rotational)** data are required to provide the shock absorber servicing state.

Apart from ensuring that the absorber is operating properly, **shock** and **acceleration** data are required to measure the condition of the components and also detect hard landing events.

The condition of landing gear components may also be affected by the operation of other aircraft components. For instance, excessive brakes temperature can cause the protective coating of the landing gear to melt. Consequently, **brake temperature** data are required, in order to be associated with the condition of landing gear components that are closely located to the brakes.

In Table 5.1, we present a more requirements relevant to the characteristics of the sensing data to be collected.

Table 5.1: Sensor requirements on landing gears

Sensor set (examples)	Data usage	Solution Features			
		Number of parts monitored by a sensor	Possibility to use a sensor-enabled tag	Importance of real-time event generation	Frequency of data retrieval for decision support
<u>Sensor set 1:</u> Pressure, Volume, Temperature, Position (linear, rotational)	Shock absorber servicing state	One	No	Low	Daily
<u>Sensor set 2:</u> Shock, Acceleration, Position	Hard landing	Many	No	High	On event
<u>Sensor set 3:</u> Corrosion, Wear, Humidity	Component corrosion and wear indication	Possibly one	Yes	Low	Possibly monthly
<u>Sensor set 4:</u> Load, Strain, L.G. Position	- Hard landing - Overload event indication - Fatigue damage	Many	Probably not	Low	Weekly
<u>Sensor set 5:</u> Brake temperature	Estimate how the landing gear condition can be affected by the condition of other components/subsystems	One	Perhaps	High	During flight

5.3. Systems and networking

This category of requirements refers to the required characteristics of the system that will obtain, store, process and transmit the afore-mentioned data.

5.3.1. Data storage requirements

Data will need to be stored both on-board the parts and in the back-end system, depending on how many ISHM features will be implemented. Given the fact that the available memory on-board the parts will be limited, only key reference data is recommended to be stored in that memory. Also, accessing data on tags is limited if the tags are not networked and regularly synchronized with an off-board database.

5.3.2. Sensor data processing

Sensor data processing aims at the detection of trends indicative of the condition of the parts. Events, such as hard landings, will need to be imminently detected through threshold values. The required level of sensor data processing or pre-processing on-board the part is not yet specified. However, hard landing detection should probably be done locally, which will also ease certification and improve safety through reliability.

Depending on the type of local data processing, different types of data need to be communicated to the backend system, like detailed data sets of readings, summaries of sensing readings and important events.

5.3.3. Data retrieval

Data should be retrieved at the back-end station at regular intervals defined by a specified number of landings. This number should be much lower than the number specified for the regular maintenance operations. In addition, in case of serious incidents, data should be rapidly and accurately pushed to the back-end system.

5.3.4. Data communication

There are no specified requirements as far as type of data transmission (wired or wireless communication) and available bandwidth are concerned.

5.3.5. Power management

It would be ideal if sensors are powered by the aircraft system itself, as the 7–12 years of battery life is unrealistic at the moment, especially for sensors and their conditioning circuits.

5.3.6. System scalability

Scalability is a very important requirement, especially for data storage and processing. Depending on the future applications of sensor data, there may be new requirements for the amount of data stored/processed and these changing requirements would be impossible to satisfy with an architecture that is unable to scale well. This is especially important in case of aircraft parts, as they have a long life.

5.3.7. System durability

As far as RFID tags and sensors are concerned, they should be reliably operating for 7–12 years in a harsh environment, which is the specified temporal interval between pre-scheduled overhauls.

5.3.8. Security issues

Access control and data security issues have to be seriously considered, because data may be corrupted by motivated part owners. Data synchronization – one of the research strands of the Aerospace-ID programme [4] – needs to ensure that data is updated without interference or error between on- and off-board data sources.

5.3.9. Networked systems

Sensor data storage: As far as data storage is concerned, raw and processed sensor data as well as detected events are required to be stored in databases both on-board the aircraft (on-board database) and on the back-end system (master landing gear database). No sensor data can be stored in the memory of the RFID tags, at least not with current passive tag capacity. However, M-D is considering the possibility of storing important sensor events, such as hard landings on the tags, so that information can travel with the parts.

Sensor data processing: Sensor data obtained from the sensory systems will need to be processed through different algorithms and models in order to provide the total parts' damage state, detect events and identify trends indicative of the parts' future condition.

Sensor data is required to be processed during flight, by an on-board processing system. In this way, the pilot and flight crew will be notified about important events if any, mainly related to hard landings or take-off problems. Moreover, sensor data processing during flight will enable more efficient scheduling of service operations on ground, minimising turnaround time.

Depending on the type of local data processing, different types of data will possibly be communicated to the backend system, like detailed data sets of readings, summaries of sensing readings and important events.

An example of a likely networked ISHM system is depicted in Figure 5.1.

5.4. Environmental constraints

This category refers to the restrictions on the nature of the solution imposed by environment or other parameters.

Range of conditions under which the system must operate: The system will need to operate in a highly metallic environment. Moreover, it will need to operate efficiently under high temperature and humidity conditions which are not yet clearly specified.

Required size and shape of tags and sensors: Some components are very small and as a result the size of the deployed tags and sensors will be an issue. There is a requirement to deploy the minimum amount of sensors possible to satisfy the requirements relevant to sensor data characteristics.

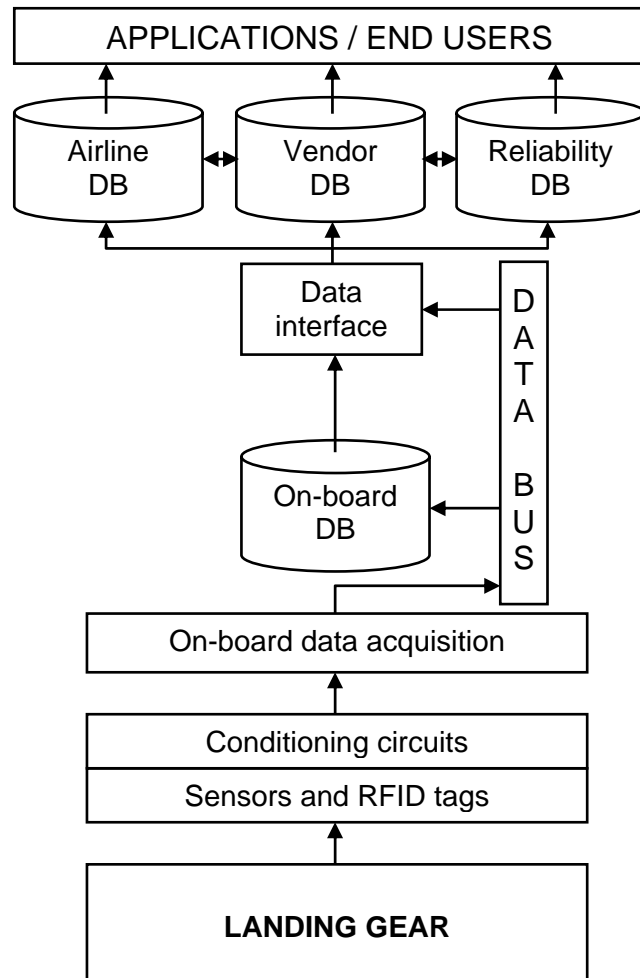


Figure 5.1: Hypothetical landing gear monitoring system

5.5. Criteria for solution selection

The most important requirements of M-D in choosing between different solutions are the following:

System reliability: The installed system should be highly reliable. It is required to operate reliably in a highly metallic environment and also withstand high humidity and shock conditions. Hence, the shielding of sensory and tag systems will need to be carefully designed. Furthermore, the afore-mentioned systems should be optimally located on the landing gear parts in order to minimize their exposure to harsh conditions.

Size and weight of tags and sensors: Given the limited size of some landing gear components, the size of tags and sensors to be mounted onto them will be an issue. Moreover, the total weight of the landing gear is required not to exceed the prescribed limits and should be kept as low as possible. As a result, there is a requirement to deploy the minimum amount of sensors that can satisfy the data and system requirements previously outlined.

System durability: RFID tags should operate for 7–12 years to make it to overhaul.

Scalability: A scalable solution should be developed that will facilitate different types and sizes of landing gears.

Security and safety issues: Customized data access is required for different users.

6. Conclusions

This case study analysed the requirements for RFID-based sensor integration in the development of an ISHM for landing gears at M-D. The general aim of this project has been to point out that RFID tagging and condition monitoring (sensor deployment) projects benefit from each other and have the potential to enable special applications. While sensors provide information about condition and RFID technology provides unique identity and data storage, the combination of the two can be the establishment of a practical implementation of the “Internet of Things”, and allow instant access to system health information for end users.

7. Acknowledgements

The authors would like to thank Elodie Leiterer, Julia Payne and Andy Crowther at Messier-Dowty and Paul Clifford at Messier Services for supporting this case study project by sharing their experience and insight.

8. References

- [1] Pátkai, Béla, Theodorou, Lila, McFarlane, Duncan, Prodonoff Jr., Victor, *Identification and Condition Monitoring of Mobile Objects by ID-based Sensor Integration – A Case Study*, 2007, Auto-ID Lab, University of Cambridge, UK
- [2] Pátkai, Béla, McFarlane, Duncan, 2006, *RFID-based Sensor Integration in Aerospace*, Auto-ID Lab, University of Cambridge, UK
- [3] Brusey, James, Thorne, Alan, 2006, *Aero-ID Sensor Integration: Scope of Work*, Auto-ID Lab, University of Cambridge, UK
- [4] Suzuki, Shigeya, Harrison, Mark, 2006, *Data synchronization specification*, Auto-ID Lab Japan and Auto-ID Lab Cambridge UK
- [5] FAA Federal Aviation Regulations, Fatigue Evaluation, FAR 25.571, http://www.flightsimaviation.com/data/FARS/part_25-571.html (This website is not an official source)
- [6] D. L. Hall. *Mathematical Techniques in Multi-Sensor Data Fusion*. Artech House, Norwood, Massachusetts, 1992.

- [7] International Society of Information Fusion, <http://www.inforfusion.org/mission.htm>
- [8] US Department of Defence Guidebook,
https://akss.dau.mil/dag/Guidebook/IG_c5.2.1.2.asp
- [9] Operations and Maintenance Information Open Systems Alliance, www.mimosa.org