THE ASSET ADMINISTRATION SHELL AS A SOLUTION CONCEPT FOR THE REALISATION OF INTEROPERABLE DIGITAL TWINS OF AIRCRAFT COMPONENTS IN MAINTENANCE, REPAIR AND OVERHAUL

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Abstract

The concept of the Digital Twin (DT) is highly relevant in numerous domains from many perspectives. The possibility to solve descriptive, diagnostic, predictive and prescriptive tasks by using real-time data and diverse models offers the potential to improve processes sustainably. This also applies to the field of aircraft maintenance, where updated digital representations of an aircraft as well as its components, so called Line Replaceable Units (LRU's), are highly needed in multiple tasks. Recorded data on the condition of these LRU's as well as their mutual interaction from flight operation are of utmost value for Maintenance, Repair, Overhaul (MRO) service providers in order to carry out fault diagnosis and maintenance planning tasks more efficiently. A major challenge in this endeavour is the difficulty of accessing the data of a LRU, as this data is collected and stored in a wide variety of formats and data sources. Consequently, the necessary flow of information is hampered and restricted. The Asset Administration Shell (AAS) has proven helpful in a wide variety of Industry 4.0 application scenarios and offers the potential to be a solution concept for realising interoperable DT's. The following contribution aims to highlight the advantages of using AAS in the maintenance of aircraft components. For this purpose, typical use cases and implementation challenges of interoperable DT's in the area of MRO are illustrated. Accordingly, the use of the AAS including suitable submodels for the representation of information for the fundamental tasks of diagnosis and maintenance planning is demonstrated.

Key Words

Digital Twin, Maintenance Repair Overhaul (MRO), Asset Administration Shell, Aircraft Components, Industry 4.0

1. INTRODUCTION

Digitalisation is advancing in diverse domains, enabling the realisation of data-driven process improvements. One concept that has become increasingly important over the last few years is the Digital Twin (DT). The main idea here is to synchronise the digital representation of an asset or an entire system network of different assets with its digital counterpart(s) through an automatic data flow [1, 2]. The collected data in combination with use case specific digital models can then be used as a means to find solutions for problems of descriptive, diagnostic, predictive and prescriptive character [3–5]. The potential of DT's in the field of aircraft maintenance by incorporating real time condition data is huge. Interoperable DT's of individual aircraft components, but also of entire systems, enable accurate diagnosis and more efficient performance of maintenance activities [3, 4]. On this basis, participants along the entire value chain are enabled to develop new digital services in the interest of generating added value from the gathered data.

The prerequisite for the targeted use and networking of DT's is the elimination of prevailing information silos among the participating companies [6]. Isolated data must be combined in a semantically consistent manner to provide a uniform view of the LRU [7, 8]. Proprietary approaches, as often found in the aviation industry, are contrary to this principle. Consequently, standardised interfaces are necessary to initiate an exchange of information between different partners in the value chain [6]. In this context, the AAS, originated from the '*Plattform Industrie 4.0*' network, is a promising solution concept for implementing interoperable DT's in aircraft maintenance. It represents a standardised digital representation of an asset in type as well as instance phase [9]. Assets can be physical or non-physical in this respect [6, 9]. In theory, DT's can be described by the AAS in any granularity and relation to each other [10]. The AAS is often also referred to as the concrete implementation of the DT in Industry 4.0 [6]. In recent years, the *'Plattform Industrie 4.0'* has published successive specifications of the AAS intended to help potential users with modelling. Via standardised application programming interfaces (API's) of the AAS, data and services can be made available for different application systems of companies. In consequence service providers in the field of aircraft maintenance could potentially expand their portfolio beyond traditional physical maintenance to include additional digital services, such as customised MRO management. Vice versa, data from the airlines' flight operations could be used for condition-based fault diagnosis or predictive maintenance approaches in order to plan maintenance activities more accurately [4].

The proposed contribution aims to explain the main potentials of using interoperable DT's in aircraft MRO by incorporating the AAS. It is structured as follows: Sec. 2 outlines basic information on interoperable DT's and the AAS. Based on this, Sec. 3 exemplary explains use cases of interoperable DT's in the field of aircraft component maintenance. Essential challenges and necessary requirements to be considered for the realisation of interoperable DT's are introduced in Sec. 4. Accordingly, a solution concept involving the AAS is presented intending to promote the elimination of the prevailing information silos. In this course, pertinent submodels and data, derived from the information needs of the use cases, are depicted. Subsequently, the possibilities of information population in the AAS are featured. A summary and an outlook on possible extensions and research aspects to be deepened conclude the contribution in Sec. 6.

doi: 10.25967/570274

2. BACKGROUND

In the following, the pertinent basics for the contribution will be explained. A short introduction to interoperable DT's as well as the AAS lays the foundation for the solution concept to be derived.

2.1. INTEROPERABLE DIGITAL TWINS

A variety of definitions concerning the DT have been published, differing from each other in the degree of detail. One of the first definitions in the manufacturing domain was introduced by Michael Grieves et al. [2]. The presented concept for a virtual product representation features all relevant information of the physical counterpart with the aim to manage this over the entire product lifecycle. Essential parts of the DT system have been its physical and virtual space as well as data flows in between. A frequently used definition that is based on this concept is given by Kritzinger et al. [1]. In this case, digital models, digital shadows, and DT's are distinguished based on their level of integration, realized by an automatic data flow. Thus, digital models have only manual data exchange with the physical space. In the case of a digital shadow, there is at least a unidirectional automatic data flow towards the digital object. A DT, on the other hand, is characterized by an automated data flow from the physical to the digital object and vice versa. Stark et al. [11] differentiate between digital master, digital shadow and DT. In this case, prototypical and universal models are stored in the digital master, which are instantiated only when an object is put into operation. The digital shadow describes the data recorded by the object during the lifecycle phase of operation. A DT is only generated through the interaction of the instantiated digital master with the digital shadow, e.g., in the form of a goal-oriented application for a validated model of a specific use case.

More recent publications also distinguish themselves through certain additional capabilities and functionalities that the DT should possess. In this context, the intelligent DT is introduced, which is further characterized by cognitive capabilities in order to realize an autonomous system [12]. For the implementation, a necessary architecture is explained and the need for interfaces for the interoperability with other DT's is addressed. Complementing this, in a number of papers [12–15] it has become evident that a DT can be developed and managed for a variety of different assets interacting with each other. In this respect, the scope of possible DT's is extended to processes, products and ressources [16]. A combination of different DT's in a 'System-of-Systems' (SoS) promises considerable added value compared to the isolated use [12, 14]. For the interoperability of these different DT's, concepts for the interaction in a network are being researched [13]. According to ISO/IEC 21823-1, interoperability is „the ability for two or more systems or applications to exchange information and to mutually use the information that has to be exchanged" [17]. More specifically the interoperability between Internet of Things (IoT) components is divided into transport, semantic and syntactic interoperability [8].

From the multitude of definitions, the following can be concluded regarding the DT in the context of this contribution: The DT contains several digital artefacts or components (data, e.g. in the form of a digital shadow, digital models, calculated data etc.) connected by a data flow (see FIGURE 1). These components are managed over the various lifecycle phases and used for application-specific problems. In the broadest sense, the DT collects the changing system behavior in a data-based manner, performs analyses, makes decisions on this basis and proposes or independently implements countermeasures [18]. Interfaces to the phyisical object or asset allow synchronisation with the DT. To realise interoperability with other DT's or to access data from the DT for a range of applications, interfaces to the virtual space are required.

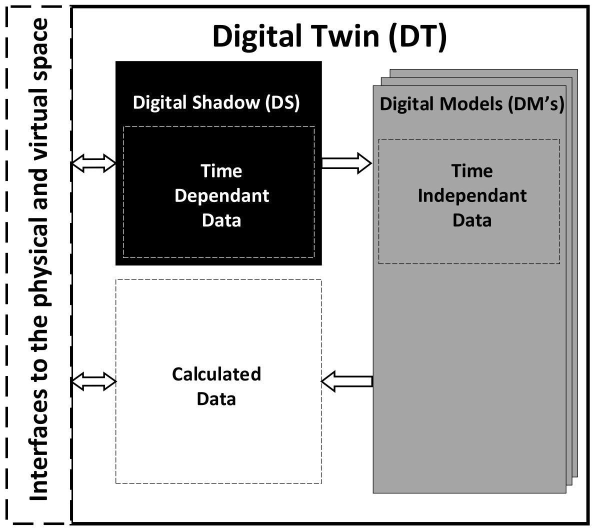

FIGURE 1. Digital Twin components [13]

2.2. ASSET ADMINISTRATION SHELL

A DT standard for the communication and management of data as well as models is a necessary foundation for the aspired interoperability, delineated in Sec. 2.1. For this purpose, the AAS, introduced by the *'Plattform Industrie 4.0'* network in Germany, enables a standardized and unified view on assets [9, 10, 19]. An AAS can be built for physical as well as non-physical assets. Most importantly, the asset considered must be clearly identifiable and retain a certain value for the company [6, 9]. An Industry 4.0 component is the combination of an asset and its AAS. In principle, the AAS delineates an information model that is technology-neutral. On this basis, different formats such as XML, JSON, OPC UA, RDF or Automation ML can be used to exchange information during different life cycle phases of the asset [19]. Typically, an AAS is divided into two parts as it is depicted in FIGURE 2. The header contains identification information (e.g. part or serial number). The body in contrast describes diverse modular submodels, comprising different submodel elements such as essential properties [9].

FIGURE 2. Exemplary AAS of an aircraft

The purpose of these submodels is to describe application-specific information. In this respect the semantics of these properties is created by incorporating references to semantic ID‘s. These in turn can refer to dicitonaries such as ECLASS [6, 9]. A partial section of the AAS meta-model is detailed in FIGURE 3.
For the information population, the appropriate data sources are incorporated at runtime via mappings and defined API‘s. Subsequently, the users can access the same data and further digital services via defined interfaces of the AAS (see FIGURE 2).

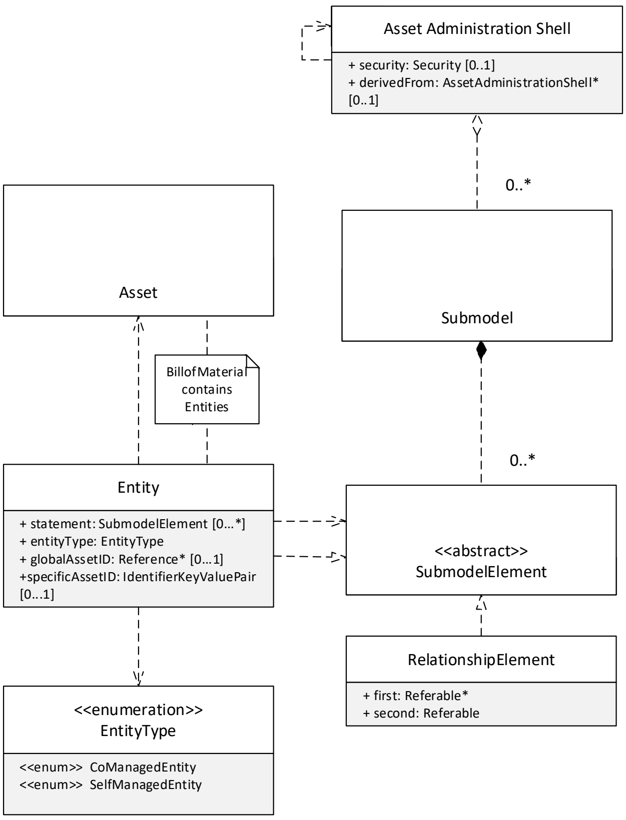

FIGURE 3. AAS meta model [9]

AAS can be modelled for an individual asset as well as for asset networks. This allows different Industry 4.0 components to interact but also to be represented in a uniform way. Thus, by using such an approach, assets can be modelled in utmost detail. In this context, connected assets are denoted as a composite asset which has references to information from individual sub-assets [19]. The basis for the connection and cooperation between AAS‘s is to formally model the possible static or dynamic relationships of the assets involved by means of properties [10]. Here, at least one characteristic of an Industry 4.0 component is related to another one. Assets which possess an own AAS are designated as 'self-managed assets'. Contrary, those to which no AAS is assigned are referred to as 'co-managed' [9]. An important requirement is that each submodel only details the relationships for its own subset of assets by means of a Bill of Material (BOM). Apart from the relationships between AAS‘s modelled with properties, references to ‘co-managed’ and ‘self-managed’ assets are specified [10, 19].

3. EXEMPLARY USE CASES FOR INTEROPERABLE DIGITAL TWINS IN THE MAINTENANCE OF AIRCRAFT COMPONENTS

In the following, two typical use cases from MRO service providers will be explained that could benefit from the use of interoperable DT‘s. Essential activities in maintenance of aircraft components are fault diagnosis and maintenance planning. Based on these activities, apposite information needs are to be derived, which possibly can be satisfied by the realisation of interoperable DT‘s.

3.1. DIAGNOSIS

Diagnosis is one of the fundamental activities in the field of maintenance concerning the identification of faults [20]. Basically, the earlier and better faults and their causes are detected, the better subsequent maintenance activities can be planned and carried out [4, 20]. To this extent, the need to obtain data associated with a LRU to describe its condition from flight operations is substantial. The major goal is to check or isolate the fault of a component respectively sub-component [21]. Diverse measured values on the condition are determined during flight operations and in the respective workshops by means of sensors and (internal) test equipment [3, 4]. Currently, many maintenance service providers primarily pursue a reactive maintenance strategy. Time series data measured and collected over the life cycle of the LRU by means of new technologies and concepts such as DT‘s enable a development towards proactive maintenance [4]. For this purpose, different digital models (physical, simulation, data-driven etc.) are incorporated in the DT, thus enabling the detection of incipient degradation or statements on the remaining useful life (RUL) [3, 4]. For the established reactive maintenance strategy, the provision of condition information from different life cycle phases of the LRU would be a sensible first step for an improved diagnosis in comparison to the current situation. However, a major problem in this context is the multitude of heterogeneous data sources and formats that have to be integrated as a means to obtain a uniform view of the asset [3].

Currently, when the LRU arrives at the MRO service provider, there is hardly any information available concerning its condition. Typically, the technicians in the workshops use a variety of different maintenance documentation (such as the CMM or Service Bulletins) to identify the possible fault and initiate troubleshooting [22]. This time-consuming task necessitates immense experience and expert knowledge. As a basis, different measured values are collected with different technical resources (e.g. test benches) in the workshop in order to carry out diagnosis [22]. The predefined troubleshootings from the CMM are not sufficient to quickly localise the cause of the fault. Often, the technicians lack further context, e.g. the possible faulty interaction with other related components, Initiated Built-In Tests (IBIT) results from Line Maintenance or error messages received from the flight operation phase of the aircraft. It is not uncommon to have so-called no-fault-founds (NFF‘s), for instance in avionics components [21]. In this example, an error message appears during flight operations or Line Maintenance. In the workshop, however, during the examinations on the test bench all tests are displayed as PASSED. In consequence, aircraft components leave the workshop without any maintenance activity having to be carried out. From an economic point of view, this results in a large number of costs (e.g. transport costs), which should be avoided, especially in view of the increased competition. The possible reasons for sending the LRU to the workshop can be manifold and sometimes remain unexplained, even though information on this may have been documented. The spectrum here ranges from a system environment in the workshop that cannot recreate the flight operation to a removal that was mistakenly carried out without any actual complaint [23]. A frequent factor that cannot be considered is whether a fault is caused by other components. For example, the fault in an elevator aileron computer (ELAC) may originate from the aileron or vice versa. However, such necessary information and context is typically not provided to the technician in the workshop. Hence, a large number of time-consuming maintenance activities are carried out intending to isolate the cause of the fault.

3.2. MAINTENANCE PLANNING

Maintenance planning in MRO workshops is characterised by great uncertainty [20, 24]. This is due to the lack of information regarding the position and condition of a LRU. As a result, excessive capacities, e.g. material, human and technical resources are planned resulting in immense costs. Likewise, many MRO service providers struggle to meet logistic KPI‘s such as lead time or on-time delivery [4, 20]. As explained in the previous section, early and accurate diagnosis would be helpful to plan necessary maintenance activities. However, with regard to the classical tasks of maintenance planning (scheduling, necessary material, necessary capacities), there is a lot of additional information from the LRU that is required from flight operations, Line Maintenance as well as from MRO workshops.

One common problem is that it is rarely known when a component will exactly arrive at the MRO workshops. On the way from the aircraft, via Line Maintenance to the workshop, a multitude of logistical activities are carried out by different companies. In this respect, there is a large amount of potential data sources that provide information about the position of the aircraft component. For capacity planning, it would be helpful if such position information could be known previously. Hence, the arrival of LRU‘s in the workshops could be estimated accurately and necessary resources could be allocated in a more cost-efficient manner. Besides, from the MRO workshops' point of view, there is a large amount of data available in unstructured, semistructured and structured form that allows crucial insights into the maintenance processes. On the one hand, to link fault symptoms with necessitated maintenance activities and resources. On the other hand, to analyse the maintenance process with regard to substantial planning activities. In general, there is a lack of visibility and transparency to identify significant influencing factors on delays. In consequence, retrospectively, it is rarely evident instantly which reasons were responsible for a prolonged lead time. Data-driven methods such as process mining have the potential to extract actual throughputs from recorded event logs and process data [25]. In this way, both logistical and maintenance activities can be viewed and analysed in an integrated manner in order to derive findings for maintenance planning. Hence, maintenance events could be enriched with further context on recorded faults, fault symptoms, necessary materials and resources. However, the normalisation of event traces is associated with great effort due to the heterogeneous data sources involved [26].

4. REQUIREMENTS

Several requirements have to be considered in a solution concept for interoperable DT‘s of LRU‘s. Aircraft are very complex machines with a multitude of systems and components from different manufacturers interacting directly and indirectly with each other. Within the life cycle of an aircraft, the installed aircraft components may change considerably compared to the state at the time of introduction. This is partly due to the fact that LRU‘s, for instance, are removed from an aircraft but not necessarily reinstalled in it. Instead, a repaired component can also be installed in another aircraft of the fleet. In this respect, separate LRU‘s are connected to a large number of different components throughout their life cycle. It is advisable to determine separate DT’s for the respective aircraft components. The specifications of DIN 77055 for the definition of life cycle records of maintenance items can be used as a guideline with the intention of selecting pertinent aircraft components. Based on this, the following requirement can be defined:

R1: The DT of an aircraft and its aircraft components should be modular. Consequently, all major components and systems should have a separate DT. The structure of individual DT‘s should correspond to the physical structure of the aircraft. In this regard, the possibility of horizontal and vertical integration with other DT‘s is imperative.

A significant problem in the effective and efficient use of DT‘s in aircraft components maintenance is the multitude of heterogeneous data sources that contain potentially interesting information and knowledge. Usually, there are diverse proprietary interfaces from different companies, which, as elaborated in Sec. 3, severely limit the exchange of information [6, 8]. Uniform access to data of the LRU is thus made much more difficult. The provision of standardised API‘s for an asset with an associated information model is potentially more effective. This would allow to accelerate access to relevant data and models of the DT.

R2: For realising interoperable DT‘s of aircraft components, digital artefacts (data and use case specific digital models) encompassing the entire life cycle must be made available via defined, standardised interfaces. For this purpose, a suitable and standardised meta-model should be used to characterise DT‘s. Furthermore, a concept for access rights should be included in order to make valuable data only available to the desired target groups.

The maintenance process is a very complex task in many respects. In the various lifecycle phases of a LRU, a large amount of information and digital models (simulation, physical, data-driven) are demanded for a wide variety of tasks, as previously indicated in Sec. 3. Within the DT of an aircraft component and during the lifecycle phase of maintenance, such different digital models can be reused [4]. Each of these is intended to satisfy the different views and information needs of the respective stakeholders. Major problems here are the differences in semantics and syntax between different data sources. Thus, integration and linkage are significantly hampered. Access to such data and models is either not possible at all or only with considerable effort [6]. In this respect, concepts and relations in information models included in the DT should be based on domain-specific industry standards or reference semantic dictionaries. This aims to guarantee the semantics of the gathered data [27].

R3: For realising interoperable DT's of aircraft components, modular submodels have to be defined depending on the use case and the information need. To ensure unambiguous semantics and secure the correct cross-company interpretation of the collected data, the information model should be based on domain-specific industry standards.

Within the life cycle of an aircraft component, as already frequently mentioned, a large amount of data is generated in different formats and in numerous heterogeneous data sources. These can include conventional IT systems such as an ERP system, containing potentially precious information about material and costs [28]. Moreover, measured values and time series of sensors from the OT level and flight operation are highly relevant for the DT of a LRU. After all, they represent the behaviour of a component and thus allow conclusions to be drawn about the existing causes of faults. In addition, there are the textual maintenance records of the employees regarding a LRU originating from the workshop. These contain potentially valuable knowledge about detected faults, fault symptoms and corrective actions. Consequently, a wide variety of possibly proprietary source formats from a wide range of participants must be able to be transformed into the target format of the information model. In this case, it should also be ensured that the transformation can be carried out bidirectionally and reliably in the case of changing target and source formats [8]. This is the prerequisite for ensuring that all necessary data can be accessed via the DT.

R4: For realising interoperable DT‘s of aircraft components, bidirectional mappings between the source formats of the individual heterogeneous data sources and the target formats of the information model (e.g. based on industry standards) are required to ensure the transformation of the data.

5. THE AAS AS A SOLUTION CONCEPT IN THE MRO OF AIRCRAFT COMPONENTS

Based on the observations made in Sec. 3 and 4, a solution concept for the use of AAS‘s of LRU‘s in MRO will be illustrated in the following. For this purpose, the information needs in the form of relevant submodels and data in the AAS (in order to fulfill ***R2***) are to be specified initially. In 5.2, an approach for the information population into the AAS is explained. Hence, potentially crucial data sources and typical formats associated are illustrated.

5.1. RELEVANT SUBMODELS AND DATA

As mentioned in Sec 2.2, the AAS has different submodels. These are necessary to characterise properties, functions, data and services of the asset, respectively the LRU. In the context of maintenance (diagnosis and maintenance planning), as described in Sec. 3, certain information needs exist that should be satisfied by considering particular submodels. Furthermore, to ensure cross-domain understanding, the information modelling should be based on appropriate industry standards (see ***R3***).

In principle, the AAS can be used to add a digital representation to each relevant aircraft component. The header of the AAS contains information that uniquely identifies the LRU. Due to the possibility of using composite AAS‘s, several individual AAS‘s can be combined (see ***R1***) and referenced in a hierarchical structure. In this form, the physical but also communication relationships between aircraft components can be captured. However, the possible relationships should be incorporated in the submodels in the form of properties. The superordinate composite asset, containing other AAS‘s, possesses the entire structure of the related LRU. A submodel ‘*CAD model*‘ might be used to model structural information. In this case each component would contain its own pertinent geometric properties and relationships. In addition, a BOM would have to be stored in the submodel, referencing related AAS‘s. Similarly, to the purely physical relationships, further models of diverse engineering disciplines involved can be added. VDI 2206 [29] potentially serves as a basis for providing a description of mechatronic systems, their modules and components as well as product, energy and information flows. By delineating such submodels, an extended context could be taken into account in maintenance tasks. Interoperable DT‘s increase the comprehensibility with regard to existing connections between LRU‘s in flight operation including a description of the exchanged signals. Thus, for instance, a complete aircraft could potentially own a composite AAS (see FIGURE 4). In this way, information from LRU‘s but also Shop Replaceable Units (SRU‘s) could also be accessed via the composite AAS of the aircraft. Furthermore, all connections between aircraft components of one level could be characterized by property relationships in the respective submodels. The signal exchange between the ELAC and the Aileron can be mentioned as an example. Hence, fine-grained models for an accurate digital representation of aircraft components could be used for various use cases. On this basis, it would also be possible to search for interactions in the data as a means to isolate fault cases.

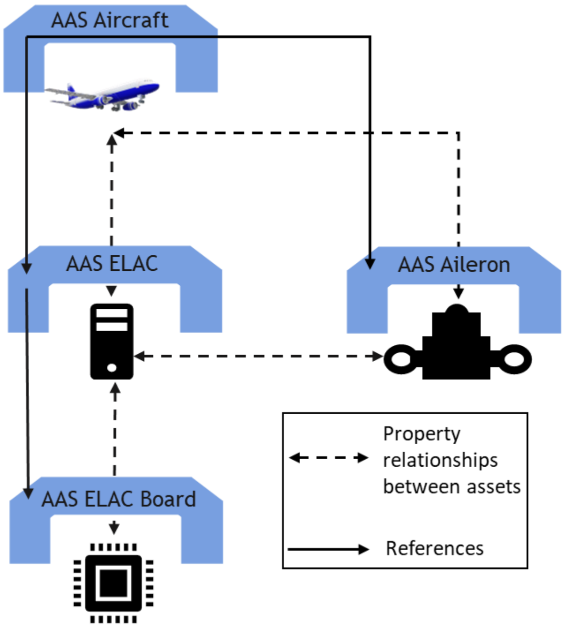

FIGURE 4. Simplified composite AAS of an aircraft

Apart from the purely structural interrelationships with other LRU‘s, each AAS of an aircraft component should possess a lifecycle record according to DIN 77005-1 [30]. The standard details a suitable information model that structures relevant information over the life cycle of a technical equipment (see FIGURE 5). Based on the information model, a variety of documented information such as maintenance documents (e.g. Component Maintenance Manual, Service Bulletins, etc.) as well as manifold measured values (operation, workshops) are included.

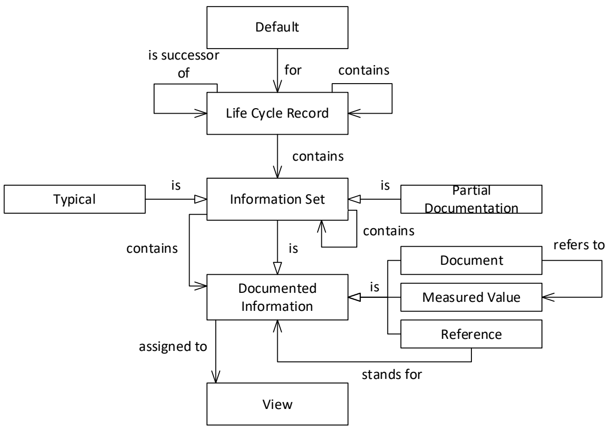

FIGURE 5. Information model of a life cycle record [30]

Furthermore, the AAS needs to take typical maintenance concepts from DIN EN 13306 [31] into account. On the one hand, to define different states of a component as well as faults. On the other hand, in an effort to clearly describe the data on maintenance activities from the workshops that have been performed on a LRU. A '*Maintenance Process*' submodel could in turn be used to define the maintenance activities actually performed on an aircraft component as well as the resources required.

Considering the information needs for the two conventional tasks of diagnosis and maintenance planning, operating data for determining the LRU condition are of great importance. Accordingly, a submodel '*Condition Monitoring*' is essential, which provides a structured description of a wide variety of measurements from different sensor data to be merged, both from operations and from the workshops. Subsequently, the data can be used for fault diagnosis activities. Combined with various models (simulation, physical, data-driven etc.), this is intended to identify faulty behavior and its cause as early as possible so that suitable corrective actions can be initiated. Conversely, this is the basis to plan necessary maintenance activities in a more systematic manner and at an early stage. Besides necessary capacities (human resources, material, test equipment etc.) can be determined. In this context, DIN ISO 17359 [32] provides recommendations on how the condition monitoring of a machine should be carried out. Moreover, appendix 1 of the standard [33] contains fundamental technical terms that can be defined in a submodel. Specifically for aircraft components, DIN EN 9721 [21] contains information on IBIT for the detection of failures as well as their isolation. This allows data on internal test procedures from flight operations and Line Maintenace to be structured and specified. In addition, parts of DIN 9721 are also suitable for managing tests from workshops on the test benches. In this respect, such test results can also be incorporated into the AAS.

In addition to the condition, the position information is of utmost importance for maintenance planning in the MRO workshops. One question that arises constantly is when to expect the arrival of a component in the workshops. In this respect, a submodel '*Track and Trace*' is helpful to detail both, the current and historical position information. DIN EN 14943 describes terms and possible properties of transport services [34]. On this basis, the location but also, for example, the planned arrival time of a LRU can be accounted for.

5.2. INFORMATION POPULATION

Before accessing the information from the AAS via the API, the pertinent data with regard to the submodels must be identified. Various stakeholders own these data in heterogeneous data sources and formats. Typically, the operator or the manufacturer of the aircraft has access to sensor data such as time series data and IBIT results from flight operations and Line Maintenance for use in condition monitoring [3, 21]. The MRO service providers, conversely, have information on maintenance activities carried out as well as measured values from technical resources such as the test benches [22]. In particular, the documentation of the maintenance records is unstructured or semi-structured. For the meaningful use of the information, it must first be converted into a structured form. For this purpose, methods from Natural Language Processing (NLP) have proven to be helpful [35]. With regard to position information, there are different data sources scattered across different stakeholders that are potentially necessary to enable seamless tracking and tracing of the LRU. Providers such as Flightradar 24 are able to locate the position of an aircraft with ADS-B data [36]. In combination with structural information of the aircraft (installed LRU's with PN and SN), aircraft components can theoretically be tracked in real time during the flight. Besides, Line Maintenance, transport service providers as well as MRO service providers have data describing the position in logistical processes. The different use of technology for tracking and tracing must be taken into account here. It can be assumed that a large number of the companies do not use real-time locating systems (RTLS) in certain sections of the journey. The use of barcodes in conjunction with the location of the barcode scanner is common in this context. In this respect, it must be decided which granularity, frequency and accuracy of the position information is demanded so that the requirements of the use cases collected are met.

To enable a uniform view of the LRU data, there must be bidirectional mappings between the original proprietary formats of the companies involved and the AAS (see ***R4***). An exemplary concept is shown in FIGURE 6. Here, the LRU's (physical layer) concerned are shown together with their AAS's (data layer), implemented using cloud technologies. In addition, exemplary data sources with relevant data to be mapped into the AAS are depicted. In some cases, further preprocessing is necessary beforehand in order to obtain structured from unstructured data, as mentioned above. The AAS should have references to the actual data sources in its respective submodels. Likewise, the necessary mappings to the data sources should be defined. Accordingly, the respective user (in this case the MRO service providers) can access the necessary information on the position and condition via the API of the AAS.

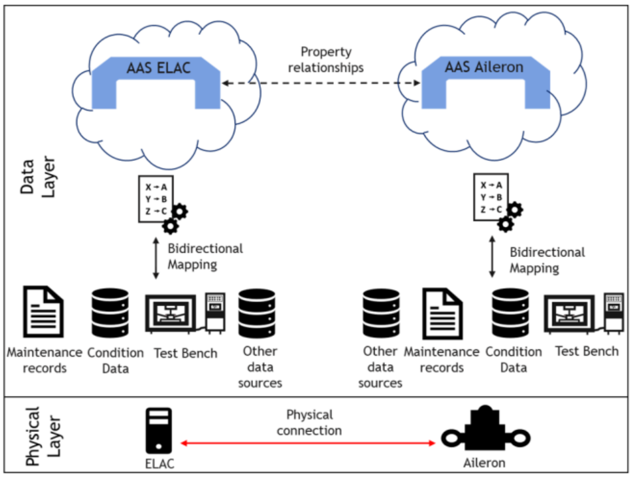

FIGURE 6. Information population of AAS, following [6]

6. SUMMARY AND OUTLOOK

In the presented contribution the need for interoperable DT's in aircraft component maintenance has been elaborated. In particular, use cases from diagnosis and maintenance planning have shown to rely on a variety of information. Thus, the aim of this contribution was to outline the advantages of using AAS for interoperable DT's of LRU's in MRO. Therefore, the basics for interoperable DT's as well as the AAS as a potential solution concept have been introduced. In addition, essential information requirements for a DT have been derived on the basis of use cases from diagnosis and maintenance planning. The consideration of requirements for interoperable DT's in the field of aircraft MRO revealed the advantageousness of using the AAS as a solution concept. On this basis, substantial submodels have subsequently been presented using appropriate industry standards. Furthermore, the information population of the respective AAS have been depicted.

Despite the potential benefits of using AAS in MRO of aircraft components, key implementation questions remain unanswered. In particular, the actual horizontal and vertical integration of DT's into a SoS is an open research question that has not yet been answered. Another major problem is the provision of data from different stakeholders along the life cycle. Many companies are not willing to disclose their gathered data to other participants for manifold reasons. The handling of intellectual property and data security must be clarified in view of this. The topic of data quality also plays an important role from various perspectives. Value for DT can only be added by means of a more targeted digitisation of the workshops intending to capture precious information on the maintenance activities actually carried out. In view of the multitude of open challenges, this paper particularly serves as a first impulse for the consideration of AAS in the domain of MRO which, however, allows much space for more in-depth research in the future.

ACKNOWLEDGEMENT

This Paper is funded by dtec.bw – Digitalization and Technology Research Center of the German Federal Armed Forces [Project ProMoDi] and BMWK – Federal Ministry for Economics Affairs and Climate Action [Project DaProKo]

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