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Product Avatar as Digital Counterpart of a Physical Individual Product: Literature Review and Implications in an Aircraft

José RÍOS[a,1], Juan Carlos HERNÁNDEZ[a], Manuel OLIVA[b] and Fernando MAS[b]
[a] *Dept. of Mechanical Engineering, Polytechnic University of Madrid, Spain*
[b] *Dept. of PLM Process and Tool Solutions, AIRBUS Group, Seville, Spain*

Abstract. 'Product Avatar' and 'Product Digital Twin' are the terms used currently to refer to the product digital counterpart of a physical product. Both terms derived from different perspectives and from different initial objectives. With a specific focus on the aerospace sector, this communication is a starting point and reviews the different topics involved in the creation of an aircraft digital counterpart, i.e. product identification, product lifecycle, product information, product configuration, product models, and software applications involved. Then, a specific section presents both approaches, 'product avatar' and 'product digital twin', together with the currently published related works. The paper ends with a discussion of the implications of creating an aircraft avatar with an industrialization-oriented perspective.

Keywords. Product avatar, digital twin, digital counterpart, aircraft avatar, PLM

Introduction

Since a few years ago, the study of the biunivocal relation between an individual physical product and its equivalent digital counterpart, which contains product related information, is the subject of research in different areas of knowledge. Derived mainly from two different research lines, and with some differences because of the objective aimed by the respective research, two concepts have been coined to name the product digital counterpart, product avatar [1] and product digital twin [2], [3]. Figure 1 illustrates the biunivocal relation between the physical and the virtual domains with a product industrialization perspective.

The relevance of having a product equivalent digital counterpart derives from the expected benefits. Stated briefly, it should allow defining, simulating, predicting, optimizing and verifying the product along its lifecycle, from conception and design, then industrialization and realization, and to usage and servicing. It should allow knowing the product past states, the current state, and estimating possible future states. For instance, it could be known, how the product was designed, how could perform under certain conditions, how it was manufactured and assembled, which components were modified and how, which maintenance operations were applied and how it is used. It should facilitate the development of product related intelligent services, such as certification, maintenance, monitoring, updating, usage predictions, etc. It should

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[1] Corresponding Author. [jose.rios@upm.es]

facilitate the access to the product information by the different product stakeholders along the product lifecycle. However, to achieve a complete product digital counterpart, overall when considering a very complex product, still requires further development and maturity of the technologies involved [2].

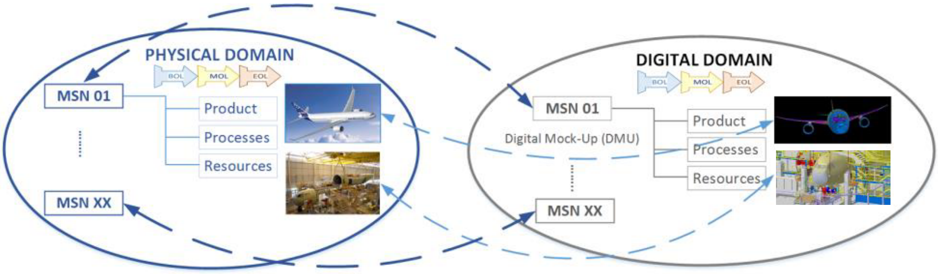

Figure 1. Biunivocal relation between the product physical domain and the product digital domain – industrialization view.

This paper has two main objectives. The first one is to provide a literature review of works dealing with issues to be considered when aiming to achieve the biunivocal relation between a physical individual product, identified by means of a 'Manufacturer's Serial Number' (MSN), and its equivalent digital counterpart. The second objective is to present, mainly from the industrialization perspective, the implications of applying the digital counterpart concept in an aircraft. According to these objectives, the paper is structured into four main sections with their corresponding sub sections.

1. Review of the topics affecting the creation of a product digital counterpart

A wide spectrum of topics are involved in the creation of a product digital counterpart equivalent to a physical product. With a focus on the aeronautic sector, the most relevant ones can be summarized as follows: product identification, product lifecycle, product information, product configuration, and product models. The following sub sections present each topic.

1.1. Product identification

It is assumed that product related information will be available in a distributed and decentralized way, and that such information will be accessible via Internet. Then, there is a need to link each individual physical product, or product instance, to its digital representations. All the digital representations constitute the product digital counterpart. It is assumed that it should be possible to locate and retrieve all the product information by means of a unique identifier for each product [4], [5], and [6]. Although typically used in RFID tags, the Electronic Product Code (EPC) [7] provides a unique identity for every physical object anywhere in the world and for its whole lifecycle. In this context, it is necessary to study the interaction with other coding systems used to name physical products in different industrial sectors, e.g.: Manufacturer's Serial Number (MSN), Tail Number (TN) or aircraft registration, and

Vehicle Identification Number (VIN). Both MSN and TN are the typical product coding systems used to identify an aircraft.

1.2. Product lifecycle

According to the Life-cycle Analysis technique, the lifecycle of a product is structured into three stages: Beginning Of Life (BOL), Middle Of Life (MOL) and End Of Life (EOL). Briefly, BOL comprises design and production of the product; MOL comprises usage and maintenance; EOL comprises different scenarios such as complete product reutilization after updates or refurbishing, product components reuse and update, decommissioning, disassembly and recycling [8].

The lifecycle of an aircraft, or of a civil aircraft program, is particularly long when compared with almost any other type of product, and it can last up to 50 years [9]. Figure 2 shows a typical distribution, over time, of the cumulative cash flow with the main stages and milestones: program launch, entry into service, end of production and aircraft retirement. The economic impact of an aircraft program and its duration emphasize the relevance of the product digital counterpart concept in the aeronautical sector.

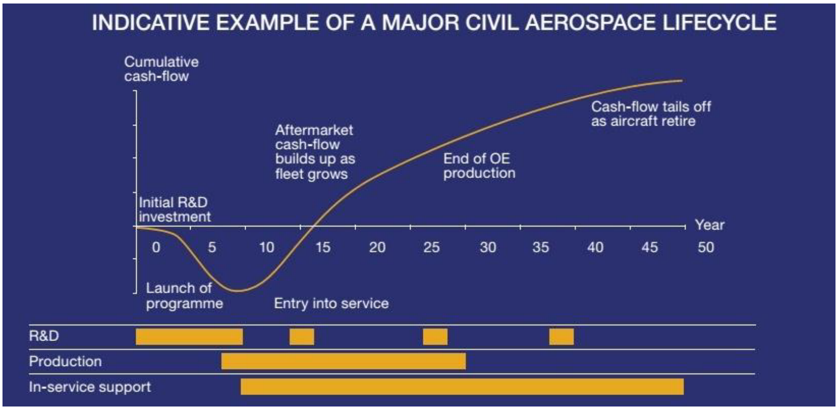

Figure 2. Typical lifecycle of a civil aircraft program [9].

From a technical perspective, the design process of an aircraft conforms to the standard RG-AERO-000-40A General recommendations for the programme management specification [10]. Since 1990, the development of an aircraft program in Airbus is conducted using concurrent engineering methods, with multidisciplinary teams, and supported by Product Lifecycle Management (PLM) applications and Computer Aided tools (CAX) to create and manage the product Digital Mock-Up (DMU) [11] [12]. Padersus [11] shows a diagram with the main phases: viability, concept, definition, development and series; and main milestones of an aircraft lifecycle at Airbus. Ultimately, the PLM system aims to support the whole aircraft lifecycle and most of its digital information.

1.3. Product information

Product data and information are created and evolve constantly along the three stages of the product lifecycle: BOL, MOL and EOL. Of special relevance is the feedback of information from the latest stages to the earliest ones, overall after the product is delivered to the client or final user. Maintenance, usage and decommissioning feedback data and information are relevant to the phases conducted during the BOL stage to apply 'design for' techniques and to predict product behaviours in future scenarios. The 'closing the information loops' approach addresses this issue [8], [13], [14]. In each stage, different phases are executed within a period, within which product information changes, evolves along different versions, increases, and generates a dynamic information structure. Such information structure should be contained in the product digital counterpart. Similarly, aircraft information changes from a dynamic state to a static state. That is because after a milestone, certain information must be 'frozen' to progress in the lifecycle. The DMU evolves along three levels of maturity [15].

The following example illustrates the implications of the current industrial practices. Commonly, a delivered and in service aircraft requires modifications, which are included within the maintenance service. Such changes affect information defined during the design phase of the aircraft; the design information is frozen after a milestone and constitutes a single structure for a set of aircrafts with a similar configuration. Currently, when a change is executed, a service bulletin is created containing the information associated with the aircraft modification, but the frozen design information is not modified, and this implies that the information of the service bulletin is not linked with the design information. Consequently, the virtual counterpart of the aircraft is not equivalent to the physical aircraft.

The dynamic aspect of the information along the BOL stage is supported by the creation of different product structures, e.g.: "as specified", "as designed", "as planned", "as prepared", and "as built". Such structures constitute the information exchanged between the different milestones of the aircraft lifecycle [11], [12], and [15]. Along the MOL stage, the dynamic aspect of the aircraft information is reflected in the product structures: "as maintained" and "as operated".

1.4. Product configuration

When considering a product physical instance as a single product, it is necessary to guarantee that its information and documentation corresponds with such product. The physical product and its digital counterpart must have a bijective relation. Configuration management is the discipline that provides a systematic approach to this issue. An aircraft has different configurations, variants to satisfy the specific requirements of each customer. The link between the aircraft DMU and the aircraft configuration management is the product configured DMU (cDMU). All the product components below the Configuration Item (CI) level, i.e. design solutions, are common to all the aircrafts with similar configuration. The cDMU provides the right 3D design data for each aircraft configuration or variant, and it has a single product structure for all the aircrafts within each configuration. In Airbus, effectivity is the concept to manage the aircraft configurations. The effectivity management is carried out by attributes, e.g. MSN [15], [16]. As illustrated in the prior section, this situation is true as long as there are no product changes once the product design information is frozen.

An approach based on the individual management of product structures, based on MSN or TN, would require to manage individually each different configuration. From each configuration, the product structure of each individual aircraft (i.e. MSN) could be created. This approach would be equivalent to the 'parent product avatar' concept, proposed by Hribernik, et al. [1], and from which the individual MSN structures could be created.

1.5. Product models

In the different phases executed along the product lifecycle stages (i.e. BOL, MOL and EOL), different types of product models are created and used to represent the product, e.g. system models, functional models, 3D geometric models, multiphysics models, manufacturing models, and usage models. Such models must be interoperable among each other and they should constitute the product digital counterpart. The correct feedback of product information is a critical factor to guarantee the biunivocal relation between the physical product and its digital counterpart [2], [3], [8], and [17].

Tuegel, et al. [2], Tuegel [17], Glaessgen and Stargel [18] focus mainly on the multiphysics models of the aircraft digital counterpart, to design and predict the structural life of an airframe, and to enhance the current approaches for aircraft certification and sustainment.

Mas, et al. [19], [20] focus on the manufacturing models, framed under the industrial Digital Mock-Up (iDMU) concept. The iDMU supports different product structures, allows addressing the issues related to the integration of functional and industrial design, and facilitates the creation of a collaborative deliverable to support the manufacturing, sustaining and servicing of the aircraft.

In addition to the proposal of the product avatar concept [1], Hribernik, et al. [21], [23], Wuest, et al. [22], focus on the product model to be used in Social Network Services. It is applied to a leisure boat product, and by means of a set of sensors, data regarding the current state of the product is accessible in a Social Network Service.

Corcelle, et al. [24] focus on item specific product information for reusability in the domain of heavy load vehicles, e.g.: built date, fabrication plant, number of total running hours, history of service operations and component replacements.

2. Main software systems to support the product lifecycle

Literature shows the issues and challenges to create and manage both the product digital counterpart and the link between the physical and the digital domains [5], [6], [8], [13], [17], [18], [23], and [24]. Causes are the complexity of the products, the complexity and volume of information, and the need to use several software systems, with their corresponding interoperability issues, along the product lifecycle, e.g. PLM, CAX, ERP, MES and others. Figure 3 shows the allocation of the software systems along the product lifecycle stages. For simplicity, the PLM tag comprises also CAX.

A PLM system facilitates and supports a strategic approach, whose aim is to implement a collaborative working process in the creation, management, dissemination and utilization of product information along its whole lifecycle [25]. Issues regarding the current capabilities and limitations of the PLM systems are identified in the literature [5], [8], [13], and [14].

Considering the three stages of the product lifecycle (i.e. BOL, MOL and EOL), the PLM systems and the CAX systems have a fundamental implementation in the BOL. Along the BOL, product design information, product industrialization information (comprising processes and resources), and product servicing information (e.g. maintenance, usage, disassembly, recycling), is defined and managed. The integration of all the information of an individual product into the DMU leads the evolution from the product oriented DMU, to the industrialization oriented DMU (iDMU), and to the service oriented DMU. However, current PLM systems treat the product as a type of product and not as an individual digital product that could have a one-to-one link with its corresponding physical one. In addition to the DMU, a product has technical documentation, e.g. work instructions, service bulletins, usage manuals, maintenance manuals, etc.; where information from the DMU is used. In the specific case of a civil aircraft, such documentation must comply with the specification S1000D [26]. This adds another component to be created, managed and traced in the product digital counterpart.

The ERP systems focus on the production physical elements, and make possible to manufacture the product according to the demand and with the requested cost. The ERP system manages each product individually, production orders are launched by MSN and each one comprises the bill of materials for each physical product. Part of the information associated with a physical product is managed and stored by an ERP system, and that is why there is a need for interoperability between PLM systems and ERP systems.

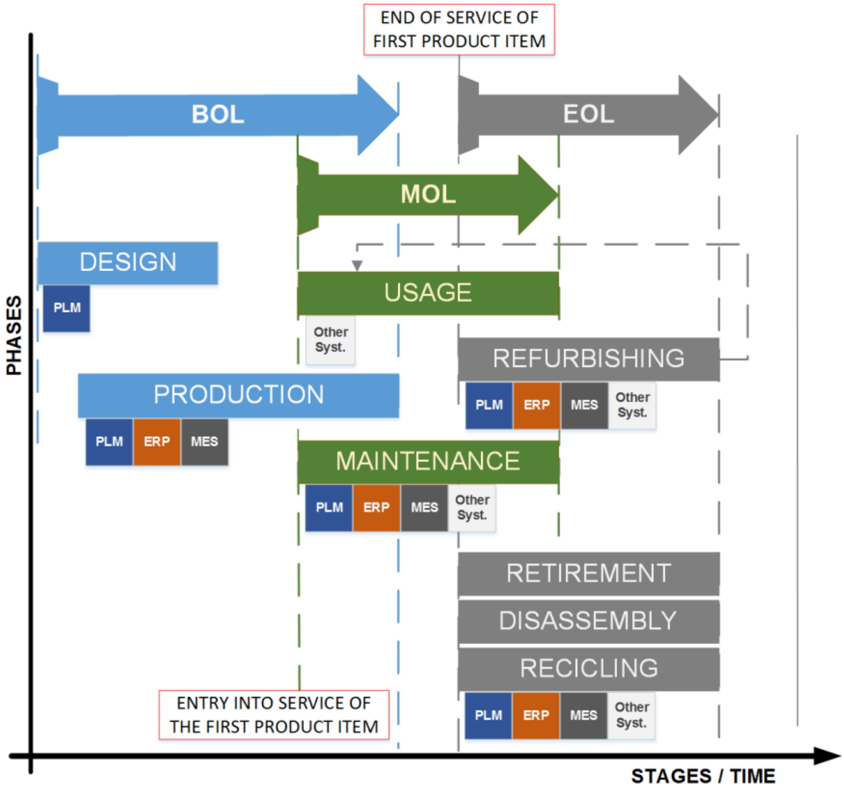

Figure 3. Stages and phases of the product lifecycle and main software systems.

The MES are mainly oriented to control different elements, e.g.: materials, personnel, machines, production orders, etc.; during the execution of the production processes and services such as maintenance. The integration of the MES systems with other systems used in the company is based on the ISA-95 model [27]. The feedback of product information from the production phase to the PLM system to update the product information and create an "as built" dynamic structure is currently a research issue [3], that is also getting special attention in the aerospace sector [18], [28].

3. Approaches to define a product digital counterpart

To define a product digital counterpart, two approaches were identified in the literature. The first approach derives from the European project PROMISE [29]. This project is one of the most relevant antecedents addressing the management and tracking of product information along its lifecycle. Several works produced in such project were already referenced in this paper: [1], [4], [5], [6], [8], [13], [14], [21], and [24]; and the proposed concept of 'product avatar' has special relevance. The second approach, derived from a different context, structural analysis in the aerospace sector, it was originally named 'airframe digital twin' [2], [17], and produced the 'digital twin paradigm' proposed by NASA and U.S. Air Force [18].

3.1. Product avatar concept

The concept of product avatar is defined as a distributed and decentralized approach to manage product information at product item level along its lifecycle [1]. The product avatar is directly linked to the concept of intelligent product and to the PLM systems [14]. According to Kiritsis [14], an intelligent product has static information (e.g. geometrical dimensions, bill of materials, processes, etc.) and dynamic information, the one that changes with time along the product lifecycle because of events. However, when considering an aircraft, since the product information (e.g. functional, industrial and service) evolves, going through different maturity states, and changes along the product lifecycle, such distinction between static and dynamic information is not particularly suitable.

Literature provides several definitions for intelligent product [21]. Summarizing, an intelligent product requires a global unique product identifier (see section 1.1) and an intelligent data unit, composed of: sensors, controller, memory and communication interface. A non-intelligent product would not have capabilities to capture data, to reason or to communicate. From the perspective of this work, the interesting aspect about the intelligent product concept is the connection with the concept of virtual product, which does not depend on the reasoning capabilities of the physical product.

From the aerospace perspective, each aircraft has an identifier (see section 1.1), has the devices to capture data about the aircraft state, and has the devices to communicate with an external source. The flight-data recorder or 'black box' would contain part of the system to capture and store in flight information [30]. However, the main issue is how to carry out and guarantee the capture of each single physical aircraft information to create and manage dynamically, the "as built" and "as maintained" structures within the PLM system. Currently, the "as built" structure represents a static view of the real final structure of the aircraft, and includes all the incidences and changes adopted during the manufacturing, assembly and testing phases, but in the form of all the associated documentation. The "as maintained" structure starts when the aircraft is delivered to the client, evolves along the MOL and EOL stages, due to the maintenance and refurbishing operations, and includes all the changes completed, together with the associated documentation.

As it was previously mentioned, the 'parent product avatar' concept [1] is interesting to implement, in a PLM system, the individual management of product structures based on the aircraft identifier (i.e. MSN or TN) generated from a 'parent common structure' or template. A product avatar is an instantiation of a parent product avatar, which provides the product configuration, the product structures and ontologies, etc.

3.2. Product digital twin concept

Defined by Glaessegen and Stargel [18], a digital twin is "*an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin*." Easily, the term 'product' can substitute the 'vehicle' or 'system' terms, and then we have the 'product digital twin' concept. The concept is originated in the aerospace certification, fleet management and sustainment environment, where special attention must be paid to the 'as-built' aircraft. The 'as-built' includes '*the configuration of the product, the material microstructure, defects, fabrication anomalies, etc.*', since virtual certification is sought [18], [31].

4. Avatar versus twin – aircraft main implications

By comparing the product avatar concept with the product digital twin concept, only two similarities are identified, but without explicitly significant differences. The first similarity is that both concepts consider a product equipped with a sensor system. The second one is that both concepts consider a product represented by different models. The definition of product avatar is more general, and the product digital twin relates to a specific engineering domain. However, when considering the meaning of the terms 'avatar' and 'twin', there is a relevant nuance. A 'twin' is '*one of two similar things that make a pair*' (Oxford Dictionary). An 'avatar' is '*a picture of a person or an animal that represents a particular computer user, on a computer screen, especially in a computer game or on social media*' (Oxford Dictionary). This may explain why the term 'twin' was used by the team aiming to create the 'as-built' digital structure of a physical product, since such structure aims representing the product digital counterpart [2], [18], and [31]. It may also explain why, product avatar published works focus mainly on making available user oriented product information in social networks and web pages [21], [22], and [23]. Literature shows that the idea of using a PLM system, containing design, manufacturing, assembly and maintenance information, to represent the product digital counterpart, is not really developed yet.

Regardless of whether the term 'avatar' or 'twin' is used, the main high level issue to be solved is how to feedback, into the digital product, the data and information derived from the manufacturing, assembly, testing and maintenance of the real physical aircraft. The feasibility of retrieving aircraft usage data from sensors located in the physical product is widely demonstrated. The creation of an aircraft digital counterpart is particularly complex due to the complexity of the product itself. A commercial aircraft may carry more than half million of different component references. In addition to the use of a PLM system to support the creation of the aircraft digital counterpart, change management processes are required to facilitate the feedback of information due to incidences and changes adopted during the manufacturing, assembly, testing and maintenance phases. From the PLM perspective, the main limitation is that current PLM systems treat the product as a type of product and not as an individual digital product, impeding the one-to-one link between the physical and the digital aircraft.

Effectivity management, based on dates or product range number, is the way to specify the applicability of the configured DMU.

5. Conclusions

The first conclusion, derived from the literature review, is that named as 'avatar' or as 'twin', the need for creating an aircraft digital similar to a physical one is clearly defined and many of the expected benefits identified.

The digital aircraft at product item level, with individual structures for each item, is a feasible approach where the '*parent product avatar*' could be combined with the current approach, based on the common structure below the configuration item level. The resulting approach, based on MSN, TN or aircraft registration number, would not add complexity to the current effectivity based approach, and it would facilitate the inclusion of manufacturing, assembly, testing, maintenance and usage incidences to each aircraft item. This would enhance the correctness of the aircraft delivery configuration, and the in service one. The feedback of the real configuration of each physical aircraft could be incorporated into the digital one, enabling the biunivocal relation between both items.

Additionally, software tools could be developed to assist in the change management process, and facilitate the application of the corresponding changes to each digital aircraft. Making the change management process simpler than the current one. As future work, the next objective is to investigate how to implement the MSN aircraft avatar, for a proof-of-concept aircraft prototype, in a commercial PLM system on the cloud. The PLM will be the central system to generate information in the BOL stage, and source of true information of the product, processes and resources, for their exploitation in the MOL and EOL stages. Ultimately, the objective is to create an Integral Digital Mock-Up (IDMU) representing the product digital counterpart/avatar/twin.

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