Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 132 (2015) 1045 – 1052
Procedia Engineering
www.elsevier.com/locate/procedia

The Manufacturing Engineering Society International Conference, MESIC 2015

PLM based approach to the industrialization of aeronautical assemblies

F. Mas[a,*], M. Oliva[a], J. Ríos[b], A. Gómez[b], V. Olmos[c], J. A. García[c]

[a]*AIRBUS Group, Av. García Morato s/n, 41011, Sevilla*
[b]*Dept. of Mechanical Eng., Universidad Politécnica de Madrid, C/José Gutiérrez Abascal 2, 28006 Madrid*
[c]*Fundación FIDETIA / IWT2 Reserch Group, U. de Sevilla, Sevilla*

Abstract

The design processes of an aircraft are highly complex and involve a large number of multidisciplinary teams. The current organizational, methodological and technological model, based on concurrent engineering working methods, creates a gap between functional design engineering and industrial design engineering. Such gap is both at the information management level and at communication level, and creates inefficiencies in the working processes. Airbus Military launched the CALIPSOneo project to investigate how to improve the current industrialization design processes and to facilitate a collaborative working environment to the multidisciplinary design teams. As a result of the CALIPSOneo project, PLM tools were adapted to develop working methods based on collaborative engineering, and particularly to develop the industrial Digital Mock-Up (iDMU). Such iDMU contains information of the product, of the assembly processes and of the resources needed during the execution of such processes. iDMU, facilitates the implementation of collaborative working procedures between functional and industrial design engineers, the 3D virtual verification and validation of the assembly processes, and the automation of extracting documentation, in several formats (paper, electronic, augmented reality), needed to execute the assembly processes at the shop floor.

Peer-review under responsibility of the Scientific Committee of MESIC 2015

Keywords: collborative engineering; iDMU; PLM; digital manufacturing; industrialization of aeronautical assemblies.

1. Introduction

In the aeronautical sector, several multidisciplinary teams are involved in the functional and industrial design

* Corresponding author. Tel.: +34 619 215 699
E-mail address: fernando.mas@airbus.com

Peer-review under responsibility of the Scientific Committee of MESIC 2015
doi:10.1016/j.proeng.2015.12.594

process. To reduce the time needed in such process, companies promote research in concurrent and collaborative engineering practices. Concurrent engineering comprises multidisciplinary teams working from the early product development stages by means of concurrent and simultaneous workflows, and it aims accelerating the product time to market by integrating different aspects of the product lifecycle within the development phase, e.g.: manufacturing, assembly, disassembly, maintenance, recycling, etc. [1]. The evolution of the information technologies and the lessons learned from applying concurrent engineering working methods, have led to the collaborative engineering approach. The collaborative engineering aims integrating both sociological and technological aspects, so a team of engineers could actively and rationally participate in a joint and agreed decision-making process, supported by a collaborative virtual working environment [2].

The European projects ENHANCE [3] and VIVACE [4] are two of the most relevant examples dealing with the concurrent and collaborative approaches in the aerospace sector. ENHANCE started in 1999, was focused on the concurrent engineering practices implementation to improve working methods and to integrate the supply chain [3]. The VIVACE project started in 2004, it took as input the results from the ENHANCE project, and it focused on the implementation of collaborative engineering methods to facilitate design oriented to objectives, knowledge management and extended enterprise integration [4]. Together with other companies, Airbus participated in both projects. The works conducted in them and company internal initiatives have led the way to the current concurrent engineering based working methods used in the company [5][6]. Although the concurrent engineering approach has allowed improving the working methods, it has also implied an organizational, methodological and technological model that creates a separation between functional design and industrial design. Such separation implies inefficiencies in the information and communication areas that affect the overall design process. The way to address such issues relies mainly in the adoption of a collaborative approach and the evolution of the software systems [2].

Product Lifecycle Management (PLM) systems and Computer Aided applications (CAX) conform the technological framework that facilitates the concurrent engineering and the collaborative work in the creation and management of the product Digital Mock-Up (DMU) [2]. The DMU is the main deliverable generated by functional design, and in a concurrent working environment, it is used as reference or master by the other phases of the product lifecycle, although its relevance declines along such lifecycle [5][6][7]. The aircraft DMU comprises 3D geometric information, functional information and manufacturing information in the form of constraints. This approach generates an inefficiency in the form of a poor integration between functional design and industrial design, causing the preservation of two different design processes. With the objective of avoiding such duality of processes, the creation of an industrialization DMU (iDMU) is proposed. The iDMU creation will imply the integration of design teams, the intensive use of digital manufacturing tools, and the support by means of CAX and PLM systems. The interoperability of the software systems (PLM and CAX) is of special relevance to succeed in the iDMU creation. The AeroSpace and Defence Industries Association of Europe (ASD) points out the interoperability challenges to support a full digital mock-up model-based engineering [8]. In this particular case, since the iDMU software framework was limited to software from a single vendor, the interoperability issue was not addressed.

The paper presents the context, the methodological approach and the results of a pilot project aiming to implement the iDMU concept. The project, named CALIPSOneo [7][9], focused on the development of an iDMU and later iDMU information deployment for the fan cowl of the aircraft A320neo. The iDMU comprised information of the product, the assembly process, assembly resources and tools and assembly work instructions.

2. Context and antecedents of the project

The product information is the main input in the project. Such information is used to create process information (how to assembly the product), to define what resources will be needed to execute the assembly process, and to define how to execute the tasks of the assembly process (assembly work instructions). Collaboration with functional design is conducted to improve the industrialization of the final product. All the information related to product, processes and resources comprise the iDMU.

The iDMU includes the definition of the network of sub processes and tasks, the allocation of the input and out product elements to each node of the process network, the allocation of the input resources to each process network node, the definition of the simulations needed to validate the tasks, and the definition of the assembly work instructions to be deployed in the shop floor. The study of the assembly work instructions deployment is also part of the conducted work. The two issues analyzed were the automatic update of the information extracted from the iDMU and the use of augmented reality techniques.

Literature shows antecedents in the use of digital manufacturing techniques and PLM tools in the 3D simulation of aero structures assembly [10], [11]. Results from prior projects conducted in Airbus Military were also taken as basis. In particular, the implementation of digital manufacturing techniques in the final assembly of the aircraft A400M [12]. The software platform was based on applications from Dassault Systèmes. CATIA V5 was used to design the aircraft components and the resources. DELMIA V5 Manufacturing Hub was customized to define and manage the processes: structure, attributes, metadata, precedence constraints, and times. DELMIA DPM V5 was used to define and execute simulations of the processes and to create assembly work instructions. From the conceptual perspective, the Manufacturing Hub customization in terms of process structure and attributes derives from the conceptual information model to support the iDMU proposed by Mas et al. [13].

3. Project Structure

The CALIPSOneo project addressed three main areas: creation of the assembly process, creation of work instructions (WIs) and deployment of WIs. Consequently, it was organized into three subprojects:

- PROTEUS: focused on the creation and maintenance of the assembly process that conforms the iDMU. It included the definition of the structures of process and resources, the allocation of the product components and resources corresponding to each process node, the validation of the process nodes and the definition of the needed 3D simulations. The main issue addressed in PROTEUS was to define the data structure and the functions needed to create the iDMU. A commercial PLM-CAX system provides generic data structures and an Application Programming Interface (API) to develop specific data structures and functions. Taking as a reference the model proposed by Mas et al. [13], a data structure and a set of functions were developed, within DELMIA Manufacturing Hub, to support the definition of an iDMU suitable for aeronautical assembly.
- MARS: focused on the creation and maintenance of work instructions (WIs) needed for the execution of the process defined in the PROTEUS sub project. The definition of the WIs must be as much automatic as possible, support multi-language and be compliant with the requirements for the WIs deployment in the shop floor. The WIs document the lowest level of process nodes. Since the execution of the assembly processes can be carried out in different industrial plants located in different countries, the language of the WI must be adapted to the language used in each location, but without having to define the WI again. This sub project used as antecedent the results from prior projects [14], and the main contribution is the solution to support multi-language.
- ELARA: focused on providing the information contained in the WIs to the shop floor personnel. It includes the creation of the augmented reality (AR) solution to show the right information to the worker when executing an assembly operation. This sub project uses the information generated in the sub projects PROTEUS and MARS, but adapted to its exploitation by means of AR. In prior projects [14], the iDMU information was extracted in the form of 3DXML files, such files were used to create files with the format used by the AR solution, and the positioning and tracking system was based in fiducial markers. ELARA provided two main contributions. The first one is the use of information from the iDMU database previously prepared ad-hoc by MARS. The second contribution is the solution to use aircraft components as natural markers for positioning and tracking.

4. Functional architecture

The applications to be used in the functional architecture of the project must satisfy the constraints of the aeronautical industrial environment, and consequently, limiting the interoperability issues. For that reason, solutions from Dassault Systèmes in their version 5 were selected: CATIA, DELMIA Manufacturing Hub, DELMIA Process Engineering (DPE), DELMIA Digital Process for Manufacturing (DPM), DELMIA Work Instructions Planning (WKI) and 3DVIA StudioPro. The applications were used interactively and by means of specific developments created using their Application Programming Interface (API). Fig 1 shows the functional architecture of the project and the flow of the main types of information elements.

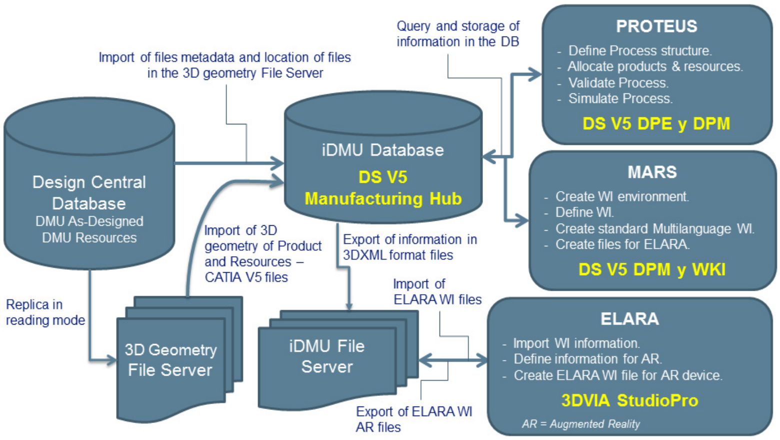

Fig. 1. Functional architecture of the project.

The functional architecture requires two databases (DB), one DB for the storage of the product functional design information and the manufacturing resources design information, and a second DB for the storage of all the industrial design information. This solution was limited by the current working methods at Airbus Military.

To accelerate the access to 3D geometric information, company's industrial plants have a replica of information contained in the Design Central DB (DCDB) in local file servers. The Industrial Design DB stores the industrial Digital Mock-Up (iDMU), the product geometric information and the resources geometric information, both imported from a 3D geometry file server. A specific utility was developed to perform the import of the 3D geometry files. The utility uses file metadata and the file storage path information. The import of the product information allowed creating in the iDMU DB a product structure similar to the one defined in the DCDB. One of the issues of this approach was the need to develop a change control utility to guarantee that the iDMU DB has the latest updated product information. The iDMU DB was created in DELMIA Manufacturing Hub using Oracle as DBMS.

The applications DPE and DPM were used in the sub project PROTEUS to define the structures: Product-Processes-Resources (PPR); which conform the iDMU. The applications DPM and WKI were used in the sub project MARS to define the work instructions (WIs) of basic tasks contained in the process structure. The WIs are part of the iDMU. The Product structure is created when the aircraft 3D geometric information files are imported. The industrial designer creates the Process and Resources structures manually. To do so, a process and resources reference data structure was defined. Such data structure specified the allowed type of process nodes, the allowed type of resource nodes, their hierarchy and attributes. Although the DPE application provides a generic model, it is necessary to define the specific data structure suitable for the type of processes to be considered, the company procedures and the purpose of the iDMU to be created. Such specific data structure is called "Plan Type Set". Process nodes are restricted by precedence and parent/child hierarchy constraints. Together with the data structure definition, upward sum functions were developed to calculate in the upper nodes the value of attributes, whose input values come from the lowest level nodes.

The application 3DVIA StudioPro was used in the sub project ELARA to develop a specific module to create assembly annotations, needed in the WIs, and to define the geometry used as reference (natural markers) in the augmented reality system. The annotations are combined with video frames, taken in real time, to show the information to the assembly worker in a tablet-PC. Once the positioning is carried out manually with the natural markers, the developed solution uses the artificial vision technique of characteristic point detection to keep the system calibrated. The development is based on the Fast detector and OpenCV artificial vision function library. 3DXML files are the information input to the 3DVIA StudioPro ELARA module. A utility was developed to import from the iDMU file server the 3DXML files with the 3D information of the industrial digital mock-up. The result of the ELARA module is a file with the annotations of augmented reality, the file is stored in the iDMU file server.

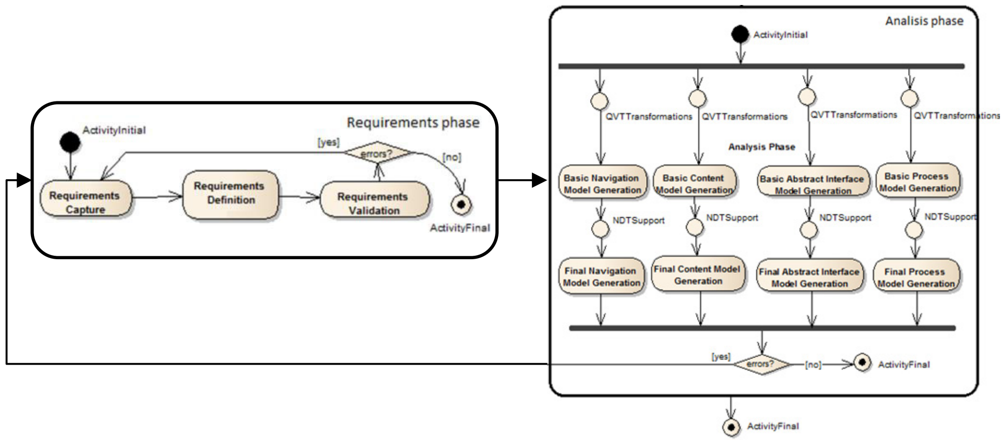

Fig. 2. Transformations from Requirements to Analysis.

5. Working methodology

NDT (Navigational Development Techniques) was the methodology adopted in this work [15]. NDT is framed under the Model Driven Engineering (MDE) paradigm [16]. MDE combines the power of concepts and its relations, using abstracts models, in order to offer suitable mechanisms for software development. This paradigm is focused on concepts and how these concepts evolved in the life cycle of a product.

Nowadays, NDT defines a set of metamodels for each phase of the software development lifecycle: Viability study, Requirements, Analysis, Design, Implementation, Testing and Maintenance. In addition, it has a set of QVT (Query View Transformations) [17] transformation rules that makes possible to generate one model from the others systematically. This implies a lower cost for the software development.

Fig. 2 shows how it is possible to generate all analysis models from Requirements phase. For example, If we focus on the model class (which represents the static structure of the system), this model is obtained from requirements. The transition (Fig. 2, stereotype «QVTTransformation») is systematized and automated, and it is based on QVT rules, which can generate a basic model. After generating each basic model, analysts can enrich and complete each model. This step (Fig. 2, stereotype «NDTSupport») is not automatic and requires expert analysts. However, NDT controls these transformations by means of a set of heuristics to ensure consistency between models.

NDT defines a set of supporting tools called NDT-Suite [18]. The main tools in NDT-Suite are: (i) NDT-Profile, which defines UML profiles in Enterprise Architect (UML analysis and design tool) for each NDT metamodel; (ii) NDT-Quality, which allows measuring, automatically, the quality of use of this methodology at each phase of the software lifecycle and checking the correct track of the MDE rules defined in NDT; and (iii) NDT-Driver, which mechanically follows all QVT rules defined in NDT. Fig 3 shows the working methodological environment in EA.

Use case diagrams were used to identify and organize functional requirements. In PROTEUS, a hierarchical structure with two levels was defined. In the first level use case diagram, four use cases were defined: Process definition in DPE, Process validation in DPM, Process simulation in DPM and Product import. Each of these use cases were decomposed into a second level use case diagram. For instance, the Process validation in DPM contained verification of product, resources and process, and verification of life cycles. Each second level use case has an activity diagram to define the flow of activities to be carried out by the main actor, in this case the manufacturing planner shows an extract, in Enterprise Architect, of the activity diagram of the use case Verification of product, resources and process.

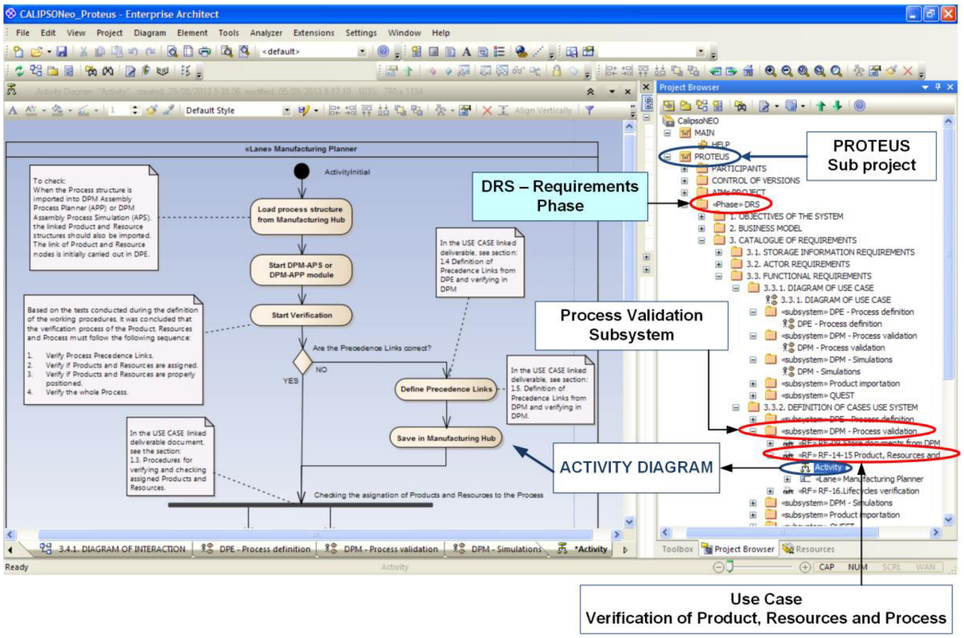

Fig. 3. Methodological working environment.

The activity diagram has three objectives. The first one is to define the sequence of tasks, as a step-by-step guide, for the main actor. Such sequence defines the working process. The second objective is to define in detail the lower level tasks to be carried out, allowing to identify where it is necessary to conduct an application development to assist the main actor or to automate a task. Once an application development is identified, a class diagram is created to specify the concepts to be implemented by such application. The third objective is to be used as basis for the definition of the diagrams for the testing phase (DPS).

6. Results

The implementation of the iDMU focused on the industrial design of the Airbus A320neo Fan Cowl, and the functional design was managed by means of the current Product Data Management platform (Design Central Database and 3D geometry file server). The update of the functional design that is imported into de iDMU DB required the development of an ad hoc software. The Product structure is created when importing the functional design information. By means of a defined colour code, the designer can identify in the working environment (DPE and DPM) the changes in the product design: new component, modified component and removed component.

Both the Process structure and the Resources structure are created in the iDMU context (DPE). The Process structure was organized into four levels: assembly line, work station, assembly operation and task; each level has its corresponding constraints (precedence, hierarchy), its attributes, the allocation of products to be assembled and the allocation of resources needed to execute the process node. Once the PPR structures are defined, the system determines the product and the resources digital mock-up that corresponds to each process node. Considering the product and the resources allocations, and the precedence constraints for a particular process node, the system knows the assembled products in prior nodes, the resources used in prior nodes and the resources needed in the current node. As a result, in the 3D environment (DPM), the 3D context of each process node is shown to the industrial designer. In this way, simulations can be defined and used to analyze and validate the defined manufacturing solution. As a consequence of using DELMIA Manufacturing Hub, the system calculate the industrialization 3D digital mock-up, allowing the review step by step of the assembly process, select any node as initial process and control the execution of the lower level child nodes.

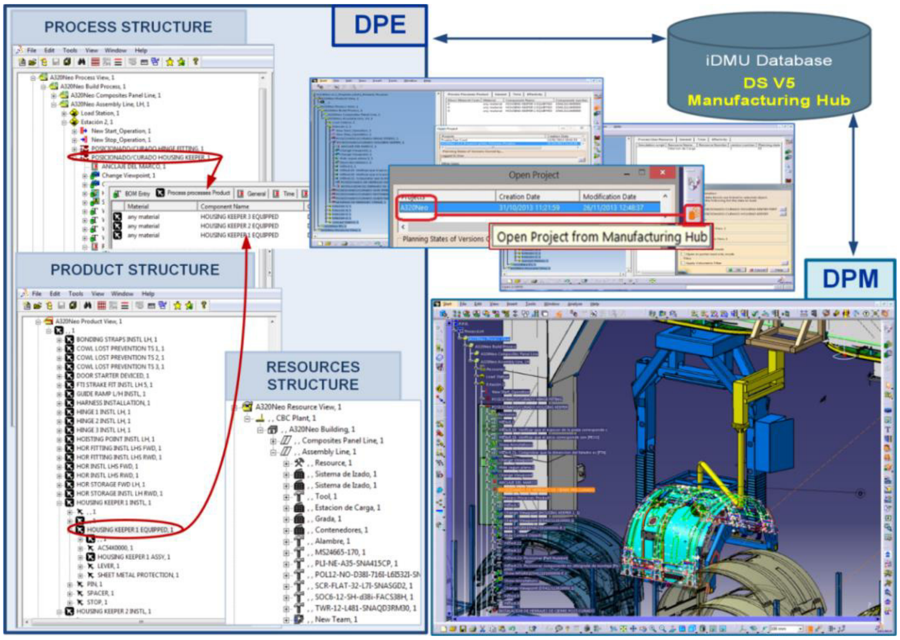

Fig. 4. Example of the PPR structures created in the PLM environment.

An important development part was the utility to define and control the consistency of the lifecycle of allocated elements of the PPR structure. Each PPR node has three possible maturity states: 'working', 'integrate' and 'released'. The utility provides a set of rules that allow controlling and alert the designer about non-coherent situations. For instance, it is not possible to assign to a process node a maturity state of 'released' when the maturity state of an allocated resource has a maturity state of 'working'. Fig. 4 shows an example of PPR structures created in DPE and an example of the 3D context in DPM.

Finally, the generation of the WIs and their use by means of the Augmented Reality (AR) system were tested. The starting point was the information contained in the iDMU, created in the PROTEUS and in the MARS subprojects. Using such information, the process information to be shown by the AR application was created.

The vision module developed in the ELARA subproject was able to track the components, selected as reference, by means of the Fast detector. The system is based on the identification of characteristics points on the physical component. Since the fuselage components are uniform, additional components were added to the AR scene to increase the number of characteristics points. Tests were performed using a tablet Asus TX300CA.

7. Conclusions

Evolve working methods, from a concurrent to a collaborative approach, requires a progressive and permanent process, led by the organization, supported by the employees and facilitated by the technological resources. The CALIPSOneo project, with a scope limited to the A320neo fan cowl, confirmed that the industrial Digital Mock-Up (iDMU) provides a suitable platform to develop the sociotechnical process needed by the collaborative engineering.

In the iDMU, the different perspectives, provided by the product functional design team, the resources design team, and the industrial design team, can be shared, modified, evolved and validated, until a common understanding and agreement about the best design solution is reached.

The project has also revealed that the general functionalities provided by the adopted PLM commercial solution requires an important research and development work to implement the data structures and functions needed to support the iDMU. Interoperability issues were not relevant.

The three main elements of the iDMU to support the collaborative approach are summarized as follows:

- The availability of a PPR context allows sharing different design perspectives, to reveal solutions that while valid for a perspective (e.g. resources design) cause problems in other perspectives (e.g. industrialization design), and to solve such issues.
- The capabilities of information reuse enable checking and validation of a high number of alternatives, allowing improving the harmonization and optimization of the design as a whole.
- The possibility of reusing 3D information, contained in the iDMU, by other software systems used in later stages of the lifecycle, facilitating the integration and avoiding problems with translation of models into intermediate formats, and making easier the use of new technologies such as augmented reality.

Finally, to mention three areas for future research and development. First one is the extension of the iDMU towards later phases of the lifecycle, in particular the servicing phase, with the objective of facilitating the documentation creation. Second one is the study of the PLM systems as the kernel to implement the concept of avatar, or digital aircraft counterpart of the physical aircraft, with the target of keeping a fully correspondence between the physical and the digital aircrafts, identified by the manufacturer serial number (MSN). A third area is the digital information interoperability issues when working in an environment with multi-vendor software solutions.

Acknowledgements

Authors would like to express their most sincere gratitude to all the colleagues from T-Systems, Dassault Systèmes, ARPA, Glenser, CEIT, FIDETIA, University of Seville, Aibus Group and Polytechnic University of Madrid, for their contribution to the CALIPSONeo project.

References

[1] X. Koufteros, M. Vonderembse, W. Doll. Concurrent engineering and its consequences. Journal of Operations Management, 19 (2001), pp.97-115.
[2] S.C.-Y. Lu, W. Elmaraghy, G. Schuh, et al. A scientific foundation of collaborative engineering. CIRP Annals - Manufacturing Technology, 56 (2007), pp.605-634.
[3] H. Braudel, N. Moïse, J.-C. Dunyach. Overall Presentation of the ENHANCE Project. Air & Space Europe, 3 (2001), pp.49-52.
[4] F. Féru, et al. An Engineering Data Management Framework for Virtual Aircraft, Proc. of the Virtual Product Development Conference, Huntington Beach, USA, 2006.
[5] T. Pardessus, Concurrent engineering development and practices for aircraft design at Airbus, Proc. of the 24th ICAS meeting, Yokohama, Japan, 2004.
[6] R. Haas, M. Sinha, Concurrent engineering at Airbus - a case study. Intl. J. of Manufacturing Tech. and Management, 6 (2004), pp.241-253.
[7] F. Mas, et al., Collaborative Engineering: an Airbus case study. Procedia Engineering, 2013, 63 (2013), pp.336-345.
[8] ASD Strategic Standardisation Group, Through Life Cycle Interoperability: a critical strategic lever for competitiveness, Rev 1.0, 9/5/2014, ASD/TLCI/01. Available at: http://www.asd-ssg.org
[9] J.L. Menéndez, F. Mas, J. Serván, R. Arista, J. Ríos, Implementation of the iDMU for an aerostructure industrialization in AIRBUS. Procedia Engineering, 63 (2013), pp.327-335.
[10] G. Chryssolouris, D. Mavrikios, N. Papkostas, et al. Digital manufacturing: history, perspectives and outlook. Proc. of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 223 (2009), pp. 451-462.
[11] J. Butterfield, D. McAleenan, C. Gibson, et al. Optimization of aircraft fuselage assembly process using digital manufacturing. J. of Computing and Information Science in Engineering, 7 (2007), pp. 269-275.
[12] J.L. Menendez, F. Mas, J. Serván, J. Ríos, Virtual verification of an aircraft Final Assembly Line industrialization: an industrial case, Key Engineering Materials, 502 (2012), pp.139-144.
[13] F. Mas, J. Ríos, J.L. Menéndez, A. Gómez. A process-oriented approach to modeling the conceptual design of aircraft assembly lines. Intl. J. of Advanced Manufacturing Techn., 67 (2013), pp.771-784.
[14] J. Serván, F. Mas, J.L. Menéndez, J. Ríos. Assembly work instruction deployment using augmented reality. Key Engineering Materials, 502 (2012), pp.25-30.
[15] M.J. Escalona, G. Aragón, NDT: A Model-Driven Approach for Web requirements, IEEE Transactions on Software Engineering, 34 (2008), pp. 370-390.
[16] D. C. Schmidt, Model-Driven Engineering, Published by the IEEE Computer Society, 39 (2006).
[17] Query/View/Transformation. www.omg.org/spec/QVT/1.1/. Release 1.1. 2011. Accessed 02/2015.
[18] J. A. García, M. Alba, L. García, M. J. Escalona, NDT-Suite: A Model-Based Suite for the Application of NDT, LNCS 7387, (2012), pp. 469–472.