20th ISPE International Conference on Concurrent Engineering
C. Bil et al. (Eds.)

doi:10.3233/978-1-61499-302-5-550

Overview on the Development of Concurrent Design Facility

Dajun Xu[a,1] , Cees Bil[b] and Guobiao Cai[a]
[a] *School of Astronautics, Beihang University, Beijing, China*
[b] *School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Melbourne, Australia*

Abstract. Concurrent Design Facility (CDF) is a workspace and information system allowing multidisciplinary experts working in a focused environment and conducting design collaboration. CDF has been proved to be an effective and efficient manner to implement Concurrent Engineering methodology. The first prototype of CDF was Project Design Center established by the Jet Propulsion Laboratory (JPL) in 1994 for the purposes of developing and implementing new tools and processes centering on concurrent engineering for space system. The most famous CDF was established at the European Space Agency (ESA) in 1998 and it has been a template for subsequent development of CDF. To date, more than 20 concurrent design environments have been developed around the world by industries, governments and universities. This paper gives an overview of the background, history and status of CDF development. Some successful applications of CDF in the field of aerospace and its benefits are outlined. Key elements of a CDF, include process, multidisciplinary team, integrated data model, appropriate facility and software infrastructure, are summarized and discussed. Some other topics related with CDF, such as Integrated Design Tool, Multidisciplinary Design Optimization (MDO), are clarified by distinguish their characteristics with CDF. Since the interaction and collaboration among experts are prominent aspect in CDF, the effect of personal behaviors and culture in CDF are also discussed. In engineering education, CDF is invaluable to lecturers by enabling the entire student team to gain cross-discipline skills and at the same time stay at the cutting edge of technology. The paper concludes with a discussion of proposed trends of CDF in the future.

Keywords. Concurrent Design Facility, Concurrent Engineering

Introduction

System engineering has characters of art and science because good system engineering requires the creativity and knowledge of systems engineers, but it also requires systems management or the application of a systematic disciplined approach. The traditional or the most ‘classical’ design methodology is the sequential approach which means a sequence of specialists working ‘in series’. The overall design passes, during the various design steps, from a technical domain specialist (working in isolation from the rest of the design team) to another, in successive time intervals. Lack of communication among the specialists cause incorrect assumptions may be adopted and the main system parameters are not monitored in real-time. This method reduces the

[1] Corresponding Author. xdj@buaa.edu.cn

opportunity to find interdisciplinary solutions and to create system awareness in the specialists. An improved method is the centralized design, where the various technical domain specialists provide subsystem design information and data to a core team of one or more system engineers. It also has the lacks of the sequential approach [1].

Concurrent Engineering is offered as an alternative to the classical approach and it provides better performance by taking full advantage of modern information technology (IT). Experts from various disciplines in the co-location could communicate in real-time and face to face. As a result of many disciplines are involved in the design process of complex systems, the concurrent approach has been proven particularly effective [1].

Concurrent Design Facility (CDF) is a workspace and information system allowing multidisciplinary experts working in a focused environment and conducting design collaboration. This paper gives an overview of the background, history and status of CDF development. Some successful applications of CDF in the field of aerospace and its benefits are outlined. Key elements of a CDF, include process, multidisciplinary team, integrated data model, appropriate facility and software infrastructure, are summarized and discussed. Some other topics related with CDF, such as Integrated Design Tool, and Multidisciplinary Design Optimization (MDO), are clarified by distinguish their characteristics with CDF. Since the interaction and collaboration among experts are prominent aspect in CDF, the effect of personal behaviors and culture in CDF are also discussed. In engineering education, CDF is invaluable to lecturers by enabling the entire student team to gain cross-discipline skills and at the same time stay at the cutting edge of technology. At last the paper concludes with a discussion of proposed trends of CDF in the future.

1. Background, History and Status of CDF

1.1. Some Teminologies

There are some teminologies about the Concurrent Design Facility and they are theory basis to support the development of CDF. Reviewing and explaining these terminologies will help us to understand the connotation of CDF.

- System Engineering

Chambers Science and Technology Dictionary provides the following very apt definition of the term 'system engineering' as used in the space field [1]: *A logical process of activities that transforms a set of requirements arising from a specific mission objective into a full description of a system which fulfills the objective in an optimum way. It ensures that all aspects of a project have been considered and integrated in to a consistent whole.*

- Concurrent Engineering (CE)

The definition of CE adopted in the ESA is [2]: *Concurrent Engineering is a Systematic approach to integrated product development that emphasizes the response to customer expectations. It embodies team values of cooperation, trust and sharing in such a manner that decision making is by consensus, involving all perspectives in parallel, from the beginning of the product life-cycle.*

- Concurrent Engineering Methodology (CEM)

The CEM is a collection of techniques, lessons learned, rules of thumb, algorithms, and relationships that has been developed for conceptual space system design. When applied, the CEM makes it possible to rapidly generate processes and tools that are customized to meet the specific requirements of a study. [3]

1.2. History of CDF

Some attempts on CE began from 1980's in the field of aerospace and defense industry. A result of survey about CE was presented in 1993 by the Integrated Process Laboratory at the Concurrent Engineering Research Center (CERC), which was established at West Virginia University in 1988 by Defense Advanced Research Projects Agency (DARPA) to promote CE in US industry. The results showed the major impetus in moving to a CE environment was seen to be the promise of reduction in overall costs and design costs, and another impetus is the need to be competitive and to improve product quality. This survey clearly indicated that the most pressing need was to foster a teamwork environment, and the greater leverage exists in teamwork and process improvement. [4]

According to literature study, the first CDF with full features, which named with the Project Design Center (PDC) was opened by the Jet Propulsion Laboratory (JPL) in June of 1994 [5]. The PDC provides a facility, with multiple rooms, for design teams to use to conduct concurrent engineering sessions. Aerospace Corporation had developed the process and the tools for CE almost at the same time and they had been successfully applied to several programs. Based on the experience of the Aerospace Corporation, the JPL contracted The Aerospace Corporation to develop CEM processes and tools for PDC. The Concept Design Center (CDC) was developed by The Aerospace Corporation in 1997, to enhance support to its customers by providing a process for bringing together the conceptual design capabilities and experts [3].

In the European space industry, concurrent engineering was also applied in the spacecraft design from the beginning of 1990'. The first example is provided by the Satellite Design Office (SDO) at DASA/Astrium, with the cooperation of the System Engineering (SE) group at the Technical University of Munich. An experimental design facility, Concurrent Design Facility (CDF), was created in the ESA Research and Technology Centre (ESTEC) at the end of 1998 and used to performance the assessment of several missions. The CDF is in effect an Integrated Design Environment (IDE) based on the concurrent engineering methodology. [6]

1.3. Status of CDF

Up to now, more than 20 CDFs have been established around the world, showed in Table 1. These CDFs scatter in United States[3][5][7]~[19], Germany[20][21], France[23], Italy[24][25], Switzerland[26][27], British[28] and Japan[29], and they can be classified by owners into government, industry and university.

1.4. Applications and Benefits of CDF

At ESA, concurrent design is primarily used to assess the technical, programmatic and financial feasibility of future space missions and new spacecraft concepts. Additionally the ESA CDF is also used for many other multi-disciplinary applications, such as

Table 1. List of Concurrent Design Facility around the world

Abb.	Full Name	Affiliation
PDC	Product Design Center	Jet Propulsion Laboratory, USA
CDC	Concept Design Center	Aerospace Corporation, USA
ASDL	Aerospace System Design Laboratory	Georgia Technical Institute, USA
SRDC	Space Research and Design Center Laboratory	Navy Postgraduate School, USA
ICDF	Integrated Concept Design Facility	TRW, USA
SSAL	Space System Analysis Laboratory	Utah State University, USA
SSR	Space System Rapid Design Center	Ball Aerospace, USA
IMDC	Integrated Mission Design Center	Goddard Space Flight Center, USA
LSMD	Laboratory for Spacecraft and Mission Design	California Institute of Technology, USA
DE-ICE	Design Environment for Integrated Concurrent Engineering	MIT, USA
Center	The Center	Boeing Military Aircraft Company, USA
HEDS-IDE	Human Exploration and Development of Space Integrated Design Environment	Johnson Space Center, USA
NAC	NRO Analysis Center	National Reconnaissance Office, USA
COMPASS	Collaborative Modeling and Parametric Assessment of Space Systems	Glenn Research Center, USA
CDF	Concurrent Design Facility	ESA, EU
S2C2	Space System Concept Center	Technical University of Munich, Germany
ISU CDF	International Space University, Concurrent Design Facility	International Space University, France
CEF	Concurrent Engineering Facility	DLR German Aerospace Center, Germany
ISDEC	Integrated System Design Center	Thales Alenia Space Italia, Italy
EPFL CDF		École Polytechnique Fédérale de Lausanne, Switzerland
CDL	Concurrent Design Laboratory	University of Glasgow, UK
MDC	Mission Design Center	JAXA, Japan

payload instrument preliminary design, System of System (SoS) architectures, space exploration scenarios, etc. [30]

Since 1994, two research teams, team-X and team-I, had conducted concurrent engineering design for space mission and space instrument in PDC of JPL. Applications of modern information systems enabled fundamental improvements to the system engineering process through the use of real time concurrent engineering. Many design teams have demonstrated dramatic savings in time and money compared with the traditional process for space systems conceptual design. In reference[5], metrics of the improvements in efficiency resulting from team-X and the PDC were showed and it should be noted that the dramatic reduction in average time to prepare proposals and very significant decrease in cost per proposal.

2. Five CE Key Elements

The ESA/ESTEC concluded the key elements on which the CDF implementation has been based are: a process, a multidisciplinary team, an integrated design model, a facility, and an infrastructure [6]. These elements are described in order below.

2.1. Process

It is a fact the space system has many interdependencies between components. This implied that the definition and evolution of each component has an impact on other components and that any change will propagate through the system. Early assessment of the impact of changes is essential to ensure that the design process converges on an optimized solution.

The process starts with a preparation phase in which some representatives of the engineering team (team leader, system engineer, and selected specialists) and of the customer meet to refine and formalize the mission requirements, to define the constraints, to identify design drivers, and to estimate the resources needed to achieve the study objectives. Then the study kick-off takes place and the design process starts. It is conducted in a number of sessions in which all specialists must participate. This is an iterative process that addresses all aspects of the system design in a quick and complete fashion. One key factor is the ability to conduct a process that is not dependent on the path followed. At any stage it must be possible to take advantage of alternative paths or use ‘professional estimates’ to ensure that the process is not blocked by lack of data or lack of decisions.

2.2. A multi-disciplinary team

Human resources are the most important and crucial element. A fundamental part of the CE approach is to create a highly motivated multi-disciplinary ream that performs the design work in real-time. The challenge, the novelty of the method, the collective approach, the co-operative environment, the intense and focused effort and a clear and short term goal are all essential elements that contribute to personal motivation.

To work effectively the team members had to accept to use a new method of working, co-operate, perform design work and give answers in real-time, and contribute to team spirit. For each discipline a ‘position’ is created within the facility and assigned to an expert in that particular technical domain. Each position is equipped with the necessary tools for design modeling, calculations and data exchange. The choice of disciplines involved depends on the level of detail required and on the specialization of the available expertise. On the other hand, the number of disciplines has to be limited, especially in the first experimental study, to avoid extended debate and to allow a fast turn-around of design iterations.

2.3. An Integrated Data Model

The design process is ‘model-driven’ using information derived from the collection and integration of the tools used by each specialist for his or her domain. A parametric-model-based approach allows generic models of various mission/technological scenarios to be characterized for the study being performed. A parametric approach supports fast modification and analysis of new scenarios, which is essential for the real-time process. It acts as means to establish and fix the ground rules of the design and to formalize the responsibility boundaries of each domain. Once a specific model is established it is used to refine the design and to introduce further levels of detail.

Each model consists of an input, output, calculation and results area. The input and output areas are used to exchange parameters with the rest of the system (i.e. other internal and external tools and models). The calculation area contains equations and specification data for different technologies in order to perform the actual modeling process. The results area contains a summary of the numeric results of the specific design to be used for presentation during the design process and as part of the report at the end of the study.

2.4. An Appropriate Facility

The team of specialists meets in the Concurrent Design Facility (CDF) to conduct design sessions. The accommodation generally comprises a design room, a meeting room and project-support office space. The equipment location and the layout of the CDF are design to facilitate the design process, the interaction, the co-operation and the involvement of the specialists. The facility is equipped with computer workstations each dedicated to a technical discipline. To the front, a Multimedia wall supporting two or three large projector screens. Each screen can show the display of each workstation, so that the specialists can present and compare design options or proposals and highlight any implications imposed on, or by, other domains.

2.5. A Software Infrastructure

An infrastructure to implement the Concurrent Design Facility outlined above requires tools for the generation of the model, integration of the domain models with a means to propagate data between models in real time, a means to incorporate domain-specific tools for modeling and/or complex calculations, a documentation-support system, and storage capability. The infrastructure must allow its users to work remotely from other Facilities, and exchange information easily between the normal office working environment and the Facility environment.

For the system model, Microsoft Excel spreadsheet was chosen for its availability and the exciting skills of the team. The distribution of the model required a mechanism to exchange relevant data between domains. This was solved by preparing a shared workbook to integrate the data to be exchanged, with macros to handle the propagation of new data in a controlled way. In some specific cases it was found more convenient not to use centralized data exchange, but rather to create a direct interface between those applications, such as the transfer of geometrical 3-D data of spacecraft-configuration to the simulation system.

3. Other Topics in CDF

3.1. Integrated Design Tool vs. CDF

Integrated design tool is a software or a multidisciplinary software environment which is developed to design aircraft/spacecraft or analyze performance, even conduct optimization [31]-[33]. It has many differences with CDF. CDF emphasize specialists in different domains to work together and to contribute their knowledge and experience to design project. CDF is a work process in dynamic and real-time manner. But integrated design tool is always developed by a small research team, even several research fellows. Design and analysis methods come from textbooks or published technology articles. Thus it is insufficient to directly get information from engineers and scientists.

3.2. MDO in CDF

There are various definitions of Multidisciplinary Design and Optimization. The AIAA defines multidisciplinary design and optimization as the optimal design of complex engineering systems which requires analysis that accounts for interactions amongst the disciplines (or parts of the system) and which seeks to synergistically exploit these interactions [34]. In the AIAA white paper [35] multidisciplinary design and optimization is characterized as a human centered environment for the design of complex systems, where conflicting technical and economic requirements must be rationally balanced. CDF essentially is a multidisciplinary design and always can get a feasible design result. Application of MDO method in CDF has started with an aim to get optimal design. Combined with the development of integrated design tool which described above, MDO will make CDF more efficient and effective.

3.3. Culture in CDF

Akira gave a very interesting research report in his master thesis [36] about concurrent engineering in different cultures. He found CE had got remarkable successes in the United States and Europe, but it is neither used nor well known in other parts of world. His thesis analyzed the CE approach to identify the key factors for successful implementation and operation from both system engineering and cultural perspectives through the case studies of an implementation failure in a Japanese organization and some successes in Euro-American organization. The CE approach is not the one-fit-all design tool and each organization needs to have its own clear goals and objects to implement the CE approach. In Japanese organization, the ambiguity of their design process, system models and responsibilities of each engineer made it difficult to build the real-time design environment, and bottom-up culture and the organization structure prevented forming the dedicated fixed team. These findings and conclusions are also suitable for other Asia countries, such as China.

3.4. Human Behaviors in CDF

The design of large-scale engineering systems requires design teams to balance a complex set of considerations. Formal approaches for optimizing complex system design assume that designers behave in a rational, consistent manner. However, observation of design practice suggests that there are limits to the rationality of designer behavior. The paper [37] explored the gap between complex system designs generated via formal design process and those generated by teams of human designers. Results show that human design teams employed a range of strategies but arrived at suboptimal designs. Analysis of their design histories suggested three possible causes for the human design teams' performance: poorly executed global searches rather than well executed local searches, a focus on optimizing single design parameters, and sequential implementations rather than concurrent optimization strategies.

3.5. CDF in Education

CDF has been successfully implemented in the aerospace engineering education, such as The Collaborative Design Environment (CoDE) at Georgia Institute of Technology [17], and Concurrent Design Facility of International Space University (ISU) [23]. During the applications of CDF, the process and collaborative model are developed. In CoDE a generalized model was formulated highlighting the key concepts and challenges of collaborative design. The model identifies communication and group cognition, problem-solving and decision-making as interdependent and critical elements. Using the generalized model as a starting point and frame of reference a detailed process was constructed by strategically aligning pertinent models of collaborative design from a variety of fields. It is important to note that the process is not specific to the CoDE and that the generalized model is flexible enough to explain collaborative design in varying degrees of complexity and scope. Many other universities are preparing to implement the CDF in the aerospace engineering education, such as RMIT of Australia [38] and BUAA of China.

4. Trends in the Development of CDF

With the rapid developing of new technologies, aerospace industry is facing the huge challenge that how to design aircraft or spacecraft mission in a fast and low cost pattern. There are many design alternatives need to be evaluated and screened. CDF based on concurrent engineering methodology is an effective and efficient approach to solve this problem. A lot of cases and experiences have showed CDF dramatically reduced the time and cost to complete the design missions compared with traditional design process. Many industry and academic research institutes in the field of aerospace are implementing or are developing their own CDF. It is obvious that more aerospace vehicle designs and flight mission assessments will be conducted in CDF and aerospace engineering education in the CDF environment will also be a trend in many universities.

Aerospace vehicle design involves different disciplinary and integrate them into a complex engineering problem. In CDF environment, specialists in each domain contribute their knowledge and experience to solve this problem. But human design decisions are always affected by some personal subjective factors and it is difficult to obtain an optimal results. Application of MDO methodologies in CDF will be powerful to accelerate convergence to optimal results by automatic data exchanging and searching progress rather than hand-on trade-off design results.

Future aircraft and aerospace vehicle design will also need to consider the cost of operation, turn-around, and maintain, etc. Thus CDF should extend the applicability across the project lifecycle. Large scale aerospace mission projects generally are undertaken by international cooperation. Collaborative distributed design ability will be requirement for the future CDF [39]-[41].

5. Conclusion

The development of CDF has a history of near 20 years from the first facility PDC was opened in 1994. Up to now, more than 20 CDFs have been established around the world and they have been implemented to design of aircraft, aerospace vehicle and space mission. Applications of modern information systems enabled fundamental improvements to the system engineering process through the use of real time concurrent engineering. Many design teams have demonstrated dramatic savings in time and money compared with the traditional process for systems conceptual design. CDF is effective and efficient has been proven by design cases and experiences of research team which apply CDF in their work.

CDF implementation based on five key elements and they are a process, a multidisciplinary team, an integrated design model, a facility, and an infrastructure. A multidisciplinary team, in other words human resources, is the core of those elements, because CDF is characterized with communication in real-time between specialists in different disciplinary domain. Process determine the efficiency of design under the environment of CDF, thus its system engineer or project lead must has some management knowledge and tips. Other three elements, model, facility and infrastructure, support the operation of CDF fluently and effectively.

CDF is not just a facility equipped with workstations, projector, and SmartBoard, and it is not a computer environment installed with an integrated design tool which could generate design results automatically. CDF essentially is a multidisciplinary design environment and Multidisciplinary Design Optimization method could promote the CDF to obtain optimal or better result. Since human factor is very important for CDF, culture of different country and human decision behaviors are also influence the implement of CDF.

CDF will continually develop in the future and more and more aircrafts, aerospace vehicles and space missions will be designed, simulated and evaluated under it. Aerospace engineering education also needs to transform student training pattern, so as to adapt the new requirements in industry.

References

[1] Fortescue, Peter, Graham Swinerd, and John Stark. Ch20 Spacecraft System Engineering. Spacecraft Systems Engineering. John Wiley & Sons, Ltd., Publication. 2011.

[2] M. Bandecchi, B. Melton, F. Ongaro. Concurrent Engineering Applied to Space Mission Assessment and Design. ESA Bulletin No.99. September 1999, pages:34-40.

[3] Aguilar, Joseph A., Andrew B. Dawdy, and Glenn W. Law. The Aerospace Corporation's Concept Design Center. 1998.

[4] M. Lawson, H.M.Karandikar. A Survey of Concurrent Engineering. Concurreing Engineering: Research and Applications . No.2, pages: 1-6, 1994.

[5] Jeffrey L. Smith. Concurrent Engineering in the Jet Propulsion Laboratory Project Design Center. 98AMTC-83.

[6] M. Bandecchi, B. Melton, B. Gardini. The ESA/ESTEC Concurrent Design Facility. Proceedings of EuSEC 2000, pages: 329-336.

[7] Julie C. Heim, Kevin K. Parsons, Sonya F. Sepahban. TRW Process Improvements for Rapid Concept Designs. 1999, pages: 325-333.

[8] Joseph A. Aguilar, Andrew Dawdy. Scope vs. Detail: The Teams of the Concept Design Center. IEEE Aerospace Conference Proceedings 2000, pages: 465-481.

[9] Robert Shishko. The Proliferation of PDC-Type Environments in Industry and Universities. 2000.

[10] F. Pena-Mora, K.Hussein, S. Vadhavkar. CAIRO: a concurrent engineering meeting environment for virtual design teams. Artificial Intelligence in Engineering, No.14, 2000, pages:203-219.

[11] Donald W. Monell, William M. Piland. Aerospace Systems Design in NASA's Collaborative Engineering Environment. IAF-99.U.1.01, 1999.

[12] Michael N. Abreu. Conceptual Design Tools for the NPS Spacecraft Design Center. Master Thesis, NAVAL POSTGRADUATE SCHOOL, 2001.

[13] Charles M. Reynerson. Developing an Efficient Space System Rapid Design Center. IEEE Aerospace Conference Proceedings 2001, pages: 3517-3522.
[14] Karpati, G., J. Martin, and M. Steiner. The Integrated Mission Design Center (IMDC) at NASA Goddard Space Flight Center. IEEE Aerospace Conference Proceedings 2002, pages: 3657-3667.
[15] Linda F. Halle, Michael J. Kramer, M. Denisa Scott. Space Systems Acquisitions Today: Systems Modeling, Design and Development Improvements, Integrating the Concept Design Center (CDC) and the NRO Analysis Center (NAC). IEEE Aerospace Conference Proceedings 2003, pages: 3647-3656.
[16] Todd J. Mosher, Jeffrey Kwong. The Space Systems Analysis Laboratory: Utah State University's New Concurrent Engineering Facility. IEEE Aerospace Conference Proceedings 2004, pages: 3866-3872.
[17] Jan Osburg, Dimtri Mavris. A Collaborative Design Environment to Support Multidisciplinary Conceptual Systems Design. AIAA 2005-01-3435.
[18] Thomas Coffee. The Future of Integrated Concurrent Engineering in Spacecraft Design. Research Report of Massachusetts Institute of Technology, 2006.
[19] Hernando Jimenez, Dimitri N. Mavris. A Framework for Collaborative Design in Engineering Education. AIAA 2007-301.
[20] Schaus, V., Fischer, P., Ludtke, D. Concurrent Engineering Software Development at German Aerospace Center – Status and Outlook. Engineering for Space, No.1, 2010.
[21] Daniel Schubert, Oliver Romberg, Sebastian Kurowski. A New Knowledge Management System for Concurrent Engineering Facilities. 4th International Workshop on System & Concurrent Engineering for Space Applications, SECESA 2010.
[22] Fischer, Philipp M., Volker Schaus, and Andreas Gerndt. Design Model Data Exchange Between Concurrent Engineering Facilities By Means of Model Transformantion. 13th NASA-ESA Workshop on Product Data Exchange 2011.
[23] Paulo Esteves, Emmanouil Detsis. Concurrent Engineering at the International Space University. 2011.
[24] M. Marcozzi, G. Campolo, L. Mazzini. TAS-I Integrated System Design Center Activities for Remote Sensing Satellites. SECESA 2010.
[25] First Studies of ASI Concurrent Engineering Facility (CEF). SECESA 2010.
[26] A. Ivanov, M. Noca, M. Borgeaud. Concurrent Design Facility at the Space Center EPFL. SECESA 2010.
[27] CO2DE: A Design Support System for Collaborative Design. Journal of Engineering Design, Vol.21, No.1, 2010. Pages: 31-48.
[28] Vasile, Massimiliano. Conccruent Design Lab in Glasgow. 2006.
[29] Kazuhik Yotsumoto, Atsushi Noda, Masashi Okada. Introduction of Mission Design Center in JAXA. 2005.
[30] M. Fijneman, A. Matthyssen. Application of Concurrent Design in Construction, Maritime, Education and Other Industry Fields. 2010.
[31] Thomas S. Richardson, Cormac McFarlane, Askin Isikveren. Analysis of conventional and asymmetric aircraft configurations. Progress in Aerospace Sciences, Vol.47, No.8, 2011. Pages: 647-659.
[32] Arthur Rizzi. Modeling and simulating aircraft stability and control – The SimSAC project. Progress in Aerospace Sciences. Vol.47, No.8, 2011. Pages: 573-588.
[33] Arthur Rizzi, Peter Eliasson, Tomasz Goetzendorf-Grabowski. Design of a canard configured TransCruiser using CEASIOM. Progress in Aerospace Sciences. Vol.47, No.8, 2011. Pages: 695-705.
[34] Anonymous, AIAA MDO technical committee, www.aiaa.org, accessed November 2004
[35] J.P. Giesing, J.F.M. Barthelemy, A summary of applications and needs, 1998, AIAA.
[36] Akira Ogawa. Concurrent Engineering for Mission Design in Different Cultures. Master of Science in Engineering and Management. Massachusetts Institute of Technology, 2008.
[37] Jesse Austion-Breneman. Observations of Designer Behaviors in Complex System Design.
[38] Cees Bil, Lachlan Thompson. Aerospace Design Education at RMIT University. AIAA 2010-9066.
[39] Liqing Fan, Huabing Zhu, Shung Hwee Bok. A Framework for Distributed Collaborative Engineering on Grids. Computer-Aided Design & Applications, Vol.4, Nos.1-4, 2007, pages: 353-362.
[40] E. Rowland Watkins, Mark McArdle, Thomas Leonard. Cross-middleware Interoperability in Distributed Concurrent Engineering. Third IEEE International Conference on e-Science and Grid Computing Proceedings, 2007, pages: 561-568.
[41] Daniel Bohnke, Bojorn Nagel, Volker Gollnick. An Approach to Multi-fidelity in Conceptual Aircraft Design in Distributed Design Environments. IEEE Aerospace Conference 2011.