OVERVIEW OF THE NEW CONCURRENT ENGINEERING FACILITY AT DLR

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ABSTRACT

In October 2008, the German Aerospace Center (DLR) inaugurated a new Concurrent Engineering Facility (CEF) in Bremen which is used mainly for design studies at the new DLR Institute of Space Systems. The CEF consists of a main conferencing room for twelve disciplines and up to seven experts or guests, and two smaller rooms for splinter meetings. So far, several one week studies have been carried out, two were dedicated to the DLR compact satellite program. As it is planned to use the CEF not only for phase 0/A studies but also during later phases of the system development cycle, the Concurrent Engineering (CE) process as well as the technical infrastructure have to meet additional requirements, related to dynamic simulations and remote collaboration. Software projects have been initiated at DLR with the objective to create a next-generation CEF infrastructure that will meet those requirements.

This paper gives an overview of the facility infrastructure and the ongoing CEF-related software projects at DLR. The AsteroidFinder project served as a first test case for the CE process. Details of first CE sessions carried out for this project and lessons learned are presented. Finally, an outlook on planned future enhancements is given.

1 INTRODUCTION

The German Aerospace Center (DLR) initiated a national compact satellite program for the creation of a series of 100 to 150 kg satellites to enable a fast and independent access to space for scientific experiments. At Bremen, the new Institute of Space Systems has the responsibility to lead this program and to integrate discipline-specific contributions from institutes located at other DLR sites. In the early design of space systems such as satellites or launcher systems, personal discussions and the exchange of ideas and data among the experts from different disciplines are the most important working technique. Therefore, with the new Concurrent Engineering Facility (CEF) a venue with advanced equipment has been established in Bremen to support such co-operative interactions as efficiently as possible.

Concurrent Engineering (CE) is a modern and effective discipline of systems engineering. Due to the increasing complexity of space systems, it becomes more and more challenging to specify optimal system configurations. During concurrent design sessions, the customer and an interdisciplinary team of engineers study some recommendable configurations of the intended space system mainly in personal discussions. This helps to overcome problems to understand the needs and requirements of a different discipline, and to find a comprehensive solution.

Such a design approach is not new (cf. [1]). For instance, the so-called Concurrent Design Facility (CDF) at the research and technology centre of the European Space Agency (ESA ESTEC) has been used for design studies for more than a decade. Based on their experience with numerous spacecraft-related CE campaigns, ESA has identified the following five CE key elements [2]:

- A process,
- a multi-disciplinary team,
- an integrated data model,
- an appropriate facility, and
- a software / hardware infrastructure.

All these items have to be addressed in the design of any CE facility. Because of time constraints set by application projects, the CEF in Bremen had to go into service as quickly as possible. For the initial phase of operation, it was therefore decided to benefit as much as possible from previous CE experience at other European sites, and at ESTEC in particular [2]. At the same time, the development of innovative concepts was initiated to improve the future application potential of the CEF.

Software is an important element of the infrastructure used at the CEF that supports parameter studies of the domain-specific experts of a CEF session and the required data exchange among them. The design engineers at ESTEC's CDF use MS Excel as front-end to the data model and as the execution environment for design calculations. A basic data model for early design phases, the so-called Integrated Design Model (IDM), has been defined by ESA. It has found a wide distribution in Europe and reached the status of a de-facto standard within the space community. For the CEF sessions carried out so far, both the IDM and an Excel-based working procedure have been adopted from ESA.

Two software projects related to the CEF are under way at the DLR institute of Simulation and Software Technology (SISTEC). The first project aims at improving the support of collaboration in a distributed environment by replacing Excel with DLR's integration framework RCE. An optional Excel plugin allows engineers to keep their accustomed working environment. In the second project, called "Virtual Satellite", dynamic simulation based on an object-oriented model repository is introduced into the CE process, with the intention to extend the use of the CEF to later phases of the system development cycle (cf. [3]). Both projects are carried out in close consultation with ESA and other European CE centers.

The remaining paper is structured as follow: In the next section, the environment and technical equipment of the CEF in Bremen are introduced, followed by a presentation of the CEF-related software development projects at DLR. A short description of the so-called "Design Workshop", a preliminary CE facility set up before the institute building in Bremen was finished, is given in section 4, together with an account of early experiences made during the AsteroidFinder [4] project which served as a first use case for the CE process. The paper concludes with a discussion of possible future extensions.

2 THE FACILITY

The facility and the installed technical infrastructure are important key elements of an effective CE approach. They have to support the individual work of team members by providing a good working atmosphere, as well as suitable and efficient tools with respect to communication, presentation, and scientific calculation. Additionally, the technical infrastructure in the CEF must be flexible to be able to response to changes of a maturing process.

2.1 The Building

The building of the Institute of Space Systems (cf. Fig. 1, left) is arranged in a U-shape. On its left ground floor, the CEF wing is located with one main conferencing room, two smaller meeting rooms, one server room, one break room, and the restrooms. To emphasize the character of the CEF as well as to offer an attractive environment for team building, a contemporary architectural design was chosen for the entire CEF wing. This comprises the superior appearance of the visible technical equipment like displays and speakers.

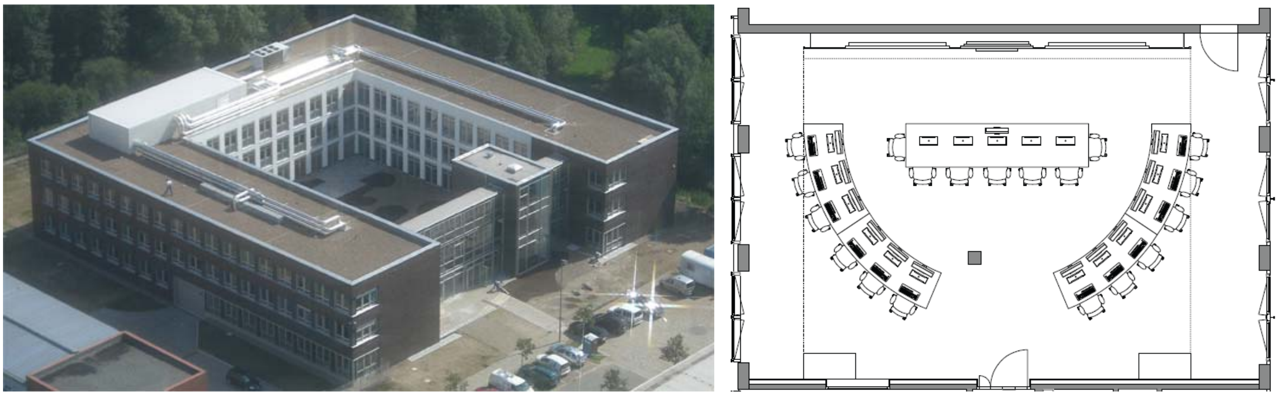

Fig. 1: The building of the Institute of Space Systems at Bremen (left) and
the layout of the main conferencing room (right)

The main conferencing room consists of twelve seats for the team members. They are arranged in a semi circle around a wide worktable where up to eight additional seats can be used for further experts or guests (cf. Fig. 1, right). The two smaller rooms available for splinter meetings are equipped with a worktable and six seats. One of them has a visible connection to the main conference room through a window.

A pleasant atmosphere is also an important prerequisite for an effective teamwork. The electrical installation in the entire building is based on a European Installation Bus (EIB) [5]. This allows the adjustment e.g. of light arrangements and light moods with a central control panel. Here, further aspects of the room settings like the alignment of jalousies or temperature and intensity of the air condition can be changed as well.

2.2 Technical Equipment

2.2.1 Media Technology

The presentation area of the main conferencing room consists of three displays. In the middle, a 65” display with an interactive overlay is placed. At both sides, 103” displays are mounted. All displays, graphic cards, and connection devices allow a full HD resolution of 1920x1200 pixels. To offer a convenient working environment, each of the twelve team members has got an own desktop computer system with a sophisticated 24” wide-screen monitor with touch screen functionality. To avoid unattractive computer cases as well as disturbing noises within the working environment, the workstation itself is located in the server room. Additionally, the limitation of the screen’s height to 40 cm ensures a free view to the other members for face-to-face discussions.

Two video cameras can record presentations and discussions in this main venue. The front camera is placed on top of the interactive display whereas the room camera equipped with a broad Pan-Tilt-Zoom is located under the ceiling in the middle of the room. For play-back of any audio media, a 5.1 surround sound system is installed. In case that some external experts not attending the session have to be consulted, a video conferencing system is installed. For that, professional microphones integrated into the desks, each shared by two members, guarantee a high quality of communication. This equipment is completed by webcams and headsets to enable personal web conferences, just in case this is needed.

Last but not least, media recorders and player devices, an all-in-one printer equipped with copy and fax options, a mobile visualizer, two wireless IP phones and a digitizer tablet for computer-aided design (CAD) are available. For the connection of notebooks or further external devices, sockets for VGA, USB, and network are provided.

At the front side of the wide worktable, one 24” touch screen is mounted to be used by the moderator or team leader. The team leader can either use one of the four table microphones while working at the desk or a professional wireless headset. If the two outer side seats are also occupied, two further microphones can be plugged in. And also at that desk, all essential sockets to connect e.g. notebooks of experts or guests are considered.

In each of the two smaller rooms, a 65” display with interactive overlay is mounted. The audio playback comes from two professional speakers. Four 24” touch screens are placed on the worktable and are connected to their workstations again stored in the server room. Furthermore, two table microphones are integrated into the desk for shared use. To complete the technical setup of these rooms, all required connections for at least two notebooks are provided.

2.2.2 Networking Technology

All servers, workstations, and notebook sockets are connected to a central 72 ports network switch. This separated network is secured by a firewall following the Adaptive Security Appliance (ASA) concept to allow the management of the communication between the workstation’s sub-networks. Through this firewall, the access into the internet is also possible. The access from the internet as well as the access into the DLR network is allowed using Virtual Private Network (VPN). A wireless network (Wi-Fi) is also provided. The access accounts are managed by the Active Directory (AD) used in the CEF.

All video devices are connected to a wall management system which is capable of routing any input signals to each output device in full HD quality. This system has 24 input and 8 output ports. It supports the option of media streaming. As inputs, the workstations of the main conferencing room as well as the video switches for the notebooks, the video conferencing system and the room cameras, the media player device, and all devices of the smaller conferencing rooms are connected. On the other hand, the signals can be routed to the three displays, the video conferencing system, the media recorder device, and devices of the smaller conferencing rooms. There is an additional separated digital audio matrix installed which controls the audio signals of microphones and head-sets, all speakers, the video conferencing system, and the media player / recorder.

2.2.3 Infrastructural Software

A managing software was developed to allow the control of all the building installations as well as the media equipment. This software can be accessed by the operator using any of the workstation’s touch screens or using her / his notebook with the managing software installed. In detail, the software provides presets for managing the configuration of different light settings, the room darkening, the air conditioning, and the speaker’s volume. Also, the inputs of all the front displays, the video conferencing system, and the tracking mode of the room cameras can be centrally managed using suitable presets.

Beside various operating systems as well as the software for the interactive boards, a media streaming software allows sharing and exchange of special screen areas between workstations. The web conferencing software will be subsequently installed to support personal communication. Furthermore, a hard disk images management system ensures that all workstations use a unique base image and that they are configured the same way. This enables the convenient initialization of all workstations before a new study is started.

3 SOFTWARE FOR CONCURRENT ENGINEERING

In order to set up a working software infrastructure at the CEF as quickly as possible, both the IDM data model and the use of MS Excel as the application software on the engineering workstations were adopted from the CDF at ESTEC. A system of Excel workbooks allows all team members to share parameters, e.g. mass and power, for further calculations or budget generations. The values are collected and distributed via a central data exchange worksheet which is controlled manually by the systems engineer. The choice of the widely-known software product MS Excel makes it easy for all subsystem experts to use the IDM after a short introduction phase.

Despite of these practical advantages, in the long run a spread-sheet-based data model, made available to design engineers through MS Excel, will not meet the user requirements for a multi-phase, multi-disciplinary working environment. Regarding the data model, the extension of the IDM parameter sets with additional information, as, for example, dynamic simulation models or CAD files, and the organization in an object-oriented structure, would be highly desirable. At EADS Astrium (Friedrichshafen, Germany) work is under way to integrate domain-specific tools with the central data model, but still keep full compatibility with the IDM of ESTEC. At the Technical University of Munich, an object-oriented data model has been developed (cf. [6], [7]) which can be used as an alternative to the IDM. This work is the basis for a new data model under development at DLR SISTEC. All future developments should closely follow the results of the related ECSS working groups E-TM-10-23A (Engineering Database) and E-TM-10-25A (Engineering design model data), because a common data model, standardized among the European space research centers and industry, would greatly facilitate the exchange of model data, and hence the collaboration in future space projects.

As to the application software infrastructure, better support for collaboration in a multi-site distributed environment, a replacement of the error-prone data exchange based on Excel, and a flexible mechanism to integrate third-party design and simulation tools are high on the priority list. To address those issues, at DLR SISTEC it was decided to introduce the integration framework RCE (Reconfigurable Computing Environment) as the basic software infrastructure for all virtual product development activities. RCE was originally developed within the German national maritime project SESIS as the basis for a large early design software for shipbuilding. The design and implementation of RCE were the responsibility of DLR SISTEC and the Fraunhofer institute SCAI. Since the end of SESIS, SISTEC has used RCE in several other projects for the provision of basic functionality such as a flexible framework for graphical user interfaces, application-transparent communication between software instances in a distributed environment, certificate-based access control, and data management including versioning and remote access [8].

As a first step towards a new software infrastructure for the CEF in Bremen, an RCE-based prototype was developed as part of a diploma thesis at SISTEC [9] . It consists of the RCE software, an Excel plugin, an object-oriented data-model in XML format, and an automatic import mechanism for IDM data into the new data model. In designing the prototype, high priority was given to making the transition from the ESTEC CDF approach (using pure Excel) to the new environment as easy as possible for CEF users. This was accomplished by

– keeping Excel as the application front-end at the engineering work places. Unlike before, however, Excel does not access the central model data directly. The Excel macros for data import and export between the central data repository and the distributed work places are replaced with synchronization functions that use RCE functionality for remote data management and notification between RCE instances.

– not changing the underlying CE process. The synchronization with the central model data for data import and export follows the same scheme as before. Therefore, the interaction between the session leader and domain specialists does not change.

– providing an automatic import function from an original IDM spreadsheet into the object-oriented RCE data model. If data have been generated in the old environment already, no manual data conversion is necessary when switching to the new software infrastructure. As compared to the IDM, the new model and the RCE data management provide benefits to the engineer, e.g. data versioning and the availability of object-oriented features such as composition and inheritance.

By encapsulating Excel as a plugin in the Eclipse-based RCE framework, the entire graphical user interface functionality of RCE and Eclipse are available in addition to the functions provided by Excel. It is also possible to replace Excel at selected work places with any discipline-specific design tool which would still be connected to the central data model through RCE's data management. This opens an easy migration path from Excel to future software solutions. It should be noted that the RCE-based distributed system is compatible with the requirements of the OCDS project [10], which is the initiative of ESA ESTEC towards a next-generation software infrastructure for Concurrent Design Facilities in Europe.

Additional software components currently under development at DLR are planned to be integrated into the same RCE environment. First of all, this regards the Virtual Satellite system which will be described in more detail in the next section. Other planned additions are the high-fidelity simulation system for hot structures (re-entry vehicles or rocket motors) under development in the DLR project IMENS-3C, and three-dimensional visualization techniques. The vision is a uniform virtual product development infrastructure for space systems that can be used over the entire system development cycle.

3.1 Virtual Satellite

The Virtual Satellite project [3] is internally funded by DLR. It does not only consider the current approach of early design phases but also supports later phases for detailed designs and developments of satellites. The main objective is that the engineers still can use this framework for the accustomed working steps in early phases e.g. in concurrent environments. But beyond that, they can exploit the underlying consistent data model for successive phases as well. This is enabled by an all-encompassing computer-aided process which integrates interfaces to discipline-specific tools and to computer simulation models. Eventually, an automation environment manages the iterative simulation run.

A core module of the framework is the system component repository to facilitate the time-consuming simulation setup. It consists of ready-to-use simulation model binaries in Simulation Model Portability standard (SMP2) format. Beside a model, a system component also holds a component description and information about geometry, constraints, and parameters. At least for early design phases, these parameters are IDM and ECSS compliant. On top of the repository, a graphical system design editor is responsible for the generation of a system simulation executable which is processed in a SMP2 runtime environment. The editor is based on RCE and allows the selection of different discipline-specific views. Here, system assemblies can be created which are immediately verified that system constraints are met.

After a simulation was performed, a comprehensive document is generated which can be analyzed in subsequent CE sessions. Additionally, the automation environment offers more advanced means for the analysis of results. For instance, one may compare the results with expected outputs defined in previous concurrent design sessions. Finally, all findings can contribute to parameter optimizations and system component improvements for further simulation iterations or new satellite design studies.

4 THE DESIGN WORKSHOP

In order to start working in the CEF efficiently and to be prepared with respect to the process and software handling, a preliminary Design Workshop (DWS) was arranged and used to gain experience of the DLR personnel in Concurrent Engineering. This facility, finished in January 2008, started with the first of two AsteroidFinder/SSB Studies, a complex compact satellite project in both technical and administrative manner. Recently, a lunar science mission study was performed within the Design Workshop environment as well. The studies were attended and supported by external experts who are also involved in the ESA ESTEC CDF activities. They were intended to guide the DLR team members during the first steps in concurrent systems engineering and handling of the CEF applications.

4.1 The AsteroidFinder/SSB Study

AsteroidFinder/SSB is a low Earth orbit satellite geared towards the search for objects Interior to Earth’s Orbit (IEOs), i.e. Near-Earth Objects (NEOs) with orbits completely contained within the Earth’s orbit. They are only observable from the ground at or very near to dusk or dawn, which makes their discovery difficult using ground-based small object surveys. As of this writing, 10 IEOs have been detected out of an estimated population of about 1000 down to a size of 100 m. Nine of these objects graze the Earth’s orbit from the inside, more being transition objects. Two of those are Potentially Hazardous Asteroids (PHA), and another comes to within PHA-definition distance to Earth’s orbit, but has a size somewhat below the PHA threshold definition. Only one true IEO orbiting deeply interior to the Earth’s orbit has been discovered. Of the next NEO classes out, approximately 5600 are known, of which almost 1000 are classified as PHA.

An Earth-orbiting search telescope is an efficient and cost-effective tool for discovering these objects. Hence, DLR has selected AsteroidFinder to be flown on its SSB satellite platform, in the frame of the German national compact satellite program. The scientific goal is to contribute to the understanding of the dynamical evolution and the cratering history of the innermost region of the Solar System, and the assessment of the impact hazard. AsteroidFinder will also test space-based detection of space debris and artificial satellites, and will contribute to NASA’s Spaceguard II goal and ESA Cosmic Vision Program activities to study NEOs. Its body-fixed 25cm wide-field telescope will continuously scan the sky in the range of 30° to 60° solar elongation. Asteroids are identified through their apparent motion. Currently in phase A, launch is planned for the end of 2011, for a one-year mission.

4.2 First CE Experiences

Each of the studies was performed in a one week full-time approach up to now, which kept the participants completely focused on the study. During this week there were periods of time planned for post processing work, e.g. subsystem specific calculations and splinter meetings as well as for specific presentations and information updates to the entire team. This led to an efficient, continuously and condensed iteration process during the study phase. A disadvantage of the one-week approach was the accumulation of other project work during this time.

The team commonly consisted of a systems engineering team, including external professional support, the discipline experts from different DLR institutes, who were responsible for e.g. mission analysis, spacecraft subsystem design and cost, as well as of several team members from industry for programmatic and scientific reasons and interests.

Extending the phase 0 approach of close networking in adjacent multi-person staff offices, with the ad-hoc use of industry standard software and commonly accessible network drives for quick information and data exchange, two DWS sessions were incorporated into the phase A of AsteroidFinder. The nature of DLR, being branched out to several major sites all across Germany, with several institutes, each, made it impossible to extend this rather informal but nevertheless efficient approach to later phases when staff outside Bremen would have to become involved on a more regular basis to make the best use of DLR’s wide variety of specialized capabilities.

Using the CEF creates an egalitarian environment of constant project-related data exchange through the CEF setup in conjunction with the actual physical presence of most or all of the participants of the project. This environment is sustained for the full duration of a session. The focus and transparency of the CEF environment suspends many of the sometimes unnerving distractions and artificial urgencies of the computerized office work culture; it does so by the very same methods of technology that created these pressures in the first place. It also dispenses with most of the artificial hierarchies and communication barriers that are only created by the fact that participants usually work at different sites of DLR or external contractors'.

This effect was clearly observed when comparing the first and the second CEF session of the AsteroidFinder phase A. Both comprised of a full working week, with most external participants arriving with the earliest train to Bremen on Monday to stay until late Friday afternoon.

The first event was dominated by many data sharing cycles which occurred on an at least daily basis, interspersed by post-processing sessions of no more than half a day, each. These came in all forms, such as in-facility homework, individually or in groups; out-facility splinter sessions in adjacent offices, or individual research in more distant facilities of the Bremen complex. (Not counting the common lunch breaks combined with a quarter-mile walk which also greatly furthered on-topic communication between the team members.)

The second event made use of the CEF data sharing mechanisms at a far lower frequency, though sometimes for more substantial changes and/or clarifications in the data set as in the first event which was of a more incremental nature. It was instead dominated by in-facility sessions of the whole group to discuss, and partially solve, the extremely inter-related and closely coupled design issues that are typical of the AsteroidFinder payload and mission. Strongly affecting the mission yield, critical optical, thermal, and operational parameters are rigidly coupled by the satellite’s accommodation layout, the orbital parameters, and the geometry of the Solar System. The related problems could not have been tackled or solved within such a short time as a week if only email and telephone or video conferencing equipment had been available. Through the unified data presentation within the CEF framework, peripheral issues were easily answered without impeding the flow of the design process by offline research as would have been the case in a distributed, non-concurrent work environment. Even more importantly, simple misunderstandings were instantly clarified, avoiding duplicated work or missed issues and precious lost time altogether. The overall gain in schedule time is hard, and maybe impossible to quantify, but estimates by participants in conversations during the later part of the week and thereafter ranged from two weeks for the individual’s specialized work package to several months for the integrated project to phase review completion. Looking at the related phase B work coming up, the higher end of the estimates seems likely closer to the truth.

5 CONCLUSION AND FUTURE WORK

With the CEF an important facility for the new DLR Institute of Space Systems in Bremen has been set up. Its design and work procedures initially adopted for space system studies largely follow the example of the CDF at ESTEC.

Early test cases confirm the usefulness for phase A studies of bringing together an interdisciplinary design team in a structured process of discussions, presentations and system budget calculations. The chosen design process proved to be effective in identifying critical design issues, communication gaps and action items for later phases. The CEF will go into routine service in 2009, with several small phase A studies and one complete phase B study.

For future studies it is planned to prolong some CE sessions to more than one week, to allow for more time for post processing. Experiments with different concurrent engineering approaches will be conducted with the objective to further optimize the concurrent engineering process at DLR.

R&D projects have been initiated towards a next-generation CEF software infrastructure. These projects are mainly motivated by the intention to extend the use of the CEF beyond the early design phase. Apart from modifications to the current data model IDM, software developments aim at a better support of cooperation in a distributed environment, the integration of additional design tools, such as an environment for dynamic simulation and test, and the inclusion of support tools, such as a team and study management, a supplier database, and a documentation management..

In all these projects, DLR is strongly committed to collaborate with all interested parties in Europe in establishing common data formats and interfaces, and to exchange CE-related software, preferably under open-source licensing.

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