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The future of Computer Aided Design and Engineering at CERN

Abstract

This note discusses design and engineering processes at CERN and Computer Aided Design and Engineering tools. The main focus of this note is Mechanical design and CAE activities and how to share and organize the data produced by CAD/CAE tools. These issues cannot be addressed without taking a global view of the engineering activities at CERN. As more and more of the detailed design work is done by external suppliers, the design processes at CERN change. Traditional design work where draftsmen are producing drawings on the request from engineers is replaced by conceptual design work done by domain specialists and engineers. Furthermore CAD and FEM tools have evolved from specialist tools to mainstream utilities mastered by most engineers. Design activities nowadays can now be carried out directly by the project engineer without the use of a design (drawing) office. This environment poses different requirements for design- and engineering support activities as well as the selection of CAE-tools. Design activities should be carried out within project teams, while a small central design office should be maintained as a centre of competence for integration studies with CAD and Digital Mockup. Increased focus on CAD-interoperability and data exchange with suppliers is recommended.

Introduction

Engineers at CERN are nowadays in charge of conceptual design, project coordination, configuration control of equipment manufactured by external suppliers and partner institutes. The design cycle is an iterative process where the team at CERN is in charge of the the concept and functional requirements, but the supplier or partner takes care of the functional and detailed design. Effective collaboration between CERN and suppliers require sharing of engineering data like 3D CAD and FEM models along with specifications, spreadsheets etc. Computer Aided Design (CAD) and Engineering (CAE) tools have become mature products and are in use within a wide range of industries for design and manufacturing (CAD/CAM) and engineering analysis (FEM).

Learning to use 3D CAD and FEM tools is part of the education for engineers both at a technical and university level. Today's engineers usually master conceptual design tools and information systems and there less need for a specialized design office with the role to produce drawings than in the past.

The computing for engineering tools at CERN include many CAD/CAM/CAE products and auxiliary tools that have been introduced in the past due to specific user requirements such as computing platform, functionality within a certain domain and so on. Over the years many of the major CAE vendors have been marginalized, while other products that started as fairly simple tools have grown into fully integrated products with a wide range of capabilities. The EUCLID 3D CAD-system is an example of an earlier high-end product that requires a complex installation and is more costly to support than modern CAD-tools. In the meantime, formerly simple design tools such as AutoCAD have grown into a suite of powerful industry branch specific design tools, including the 3D Mechanical CAD system Inventor that by a wide margin surpasses EUCLID in terms of functionality.

A replacement of EUCLID is therefore long overdue, even if EUCLID and AutoCAD are the principal tools for the design of LHC. This has been addressed by the CAD-2000 project[1] that has done a study of CERN user's requirements for CAD and the CAD-market in order to identify a future CAD system for CERN. Based on a set of requirements to cover a wide range of functionality in one single integrated system, CatiaV5 was selected as a replacement for EUCLID.

CatiaV5 is currently used in a pilot project for LEIR, that will provide experience using this tool in the CERN environment. However, before we do a wider deployment of CatiaV5 as a replacement for EUCLID, one should take a step back and look at engineering processes for the LHC accelerator and experiments and how the use of CAE-tools at CERN is likely to evolve. Key issues to be considered are:

- Engineering processes at CERN and industrial suppliers.
- CAD/CAM/CAE at CERN and industry trends.
- Training, support and IT infrastructure.
- Migration aspects (in particular for EUCLID).

Engineering processes evolve – industry trends

Changes in the design and manufacturing processes in industry apply more and more to CERN as well. In particular the following trends are changing the needs for CAE tools and processes:

- Focus on core competences, conceptual design of accelerators and detectors and their integration and installation. Partner institutes or suppliers are usually in charge detailed design and manufacturing.
- Suppliers and partner institutes should be able to share and interact with CERN design teams – interoperability is key.
- Less and less people understand 2D technical drawings, work will be based on 3D models. The 3D product model becomes the core of design and simulation activities.
- No longer traditional drawing offices, conceptual design work will be done by engineers and physicists.
- Younger engineers and physicists are computer literate and cope well with CAD-tools and PC environment. Nevertheless training courses are essential to ensure a coherent methodology and a productive design process.
- Information must be easily accessible on Internet, yet under configuration control.
- Simpler IT infrastructure, reduced complexity and number of supported tools.

[1] CAD-2000: A new CAD system for CERN. See http://www.cern.ch/CAD2000/ for details.

Main engineering processes at CERN

Design

Over the last years, CERN is following the industry trend towards increased outsourcing in order to concentrate on the core activities of CERN; Accelerators and infrastructure to support the experiments. What regards the design and engineering processes, the role of CERN is more and more to do the conceptual design only of equipment such as magnets or detectors. Detailed engineering and design are often done by partner institutes and industrial suppliers. In the cases where CERN is responsible for the complete engineering life-cycle and prototype manufacturing, the detailed design and manufacturing is often outsourced to industrial suppliers or workshops specialized in low-volume manufacturing.

Structural analysis and simulation

Calculation of strength and structural analysis are activities that are usually carried out during the conceptual design process with CAE tools such as Ansys. In cases where there are particular requirements, a detailed analysis and simulation is done based on the detailed design. Simulation of e.g. Electromagnetic fields and physics events is done with specialized simulation tools.

Integration and installation

Integration design studies with data from external partners and simulation of the installation of this equipment in experimental areas and the LHC-accelerator tunnel is another important domain of 3D design work along with conceptual design. Integration studies are better done with "Digital Mockup" type CAE-tools with real-time graphics and good import capabilities of a wide range of file formats than traditional CAD-systems for mechanical design.

Services

Services and branch-specific activities, such as piping, cabling, survey etc that require dedicated CAD-solutions are more and more done by external contractors. In this domain it is essential that CERN sticks to industry-standard CAE-tools in order to facilitate exchange of information with partners and sub-contractors.

CAD/CAM/CAE tools at CERN

EUCLID is still the main 3D CAD system at CERN with 80 seats . CERN was a pioneer with 3D CAD when it chose EUCLID in 1982 as the design application for LEP. EUCLID has been the main 3D CAD-system for LEP and LHC, but since a few years the system is in "maintenance mode", especially since the take over of Matra Datavision by Dassault. With the exception of extended size of models and support for more recent operating systems (including Windows 2000), the functionality of the EUCLID system has evolved little since 1993. Interoperability with other CAD-systems as well as FEM tools is very limited, which poses major problems for sharing of 3D data with suppliers and partner institutes. The increased need to communicate with external suppliers with other modern CAD-systems is making the case for replacing EUCLID more and more urgent.

AutoCAD is in widespread use at CERN, with more than 150 seats that are used mainly for 2D drafting, but also the 3D module Mechanical Desktop is used widely used for 3D design and integration studies. The modern 3D Mechanical system Autodesk Inventor is used in some projects, notably for conceptual design combined with structural analysis thanks to associativity with Ansys. Furthermore extended modules for AutoCAD for Civil engineering and services such as piping are in use. The CERN AutoCAD user community is more dispersed and fragmented than the EUCLID user community, but since 1996 the "CASC" committee has become a focal point for AutoCAD users and methodology at CERN.

CatiaV5 is deployed in a pilot project for LEIR[2] and is also used in other domains, such as "Digital Mock-up" and model preparation for FEM analysis. It is foreseen to use SmarTeam to manage data produced with CatiaV5.

CERN also has a limited Pro/ENGINEER installation that recently has been reduced to 1 single license for archiving and data-exchange purposes. (Additional Pro/ENGINEER installations exist within the LHC experiments.)

Furthermore RobCAD and Autodesk 3D StudioMAX are use for digital mock-ups and 3D installation studies, with CAD-models imported from EUCLID, AutoCAD and other systems. The plan is to replace RobCAD by CatiaV5 Digital Mockup.

Simple drawing tools like Visio are also increasingly being used for 2D engineering sketches and simple drawings. Interoperability between CAD and such drawing tools is therefore an issue.

Structural analysis and simulation software:

ANSYS is the main application for FEM and structural analysis at CERN. A lightweight version, DesignSpace for simulation tasks during the design process, is offered for CAD users without FEM experience. Over the last years there has been an effort to improve training and support of Ansys and to reduce the diversity of CAE tools. Ansys is complemented by ESAcomp for composite material design and StarCD for Computational Fluid Dynamics. The support policy for FEM and Structural Analysis tools at CERN is governed by the CoSAC user committee. A major requirement for FEM Analysis is efficient data exchange with CAD and effective preprocessing on CAD-data.

For field calculations and magnet design, there are tools like Opera, Tosca, Roxie and MAXWELL/Eminence. These tools are rather specific to CERN and necessary in order to validate accelerator and detector designs. The support policy for such tools is governed by the UGFC user committee.

[2] Low Energy Ion Rings (LEIR) machine, an ion accumulator for LHC.

Last but not least there are physics event simulation and off-line computing tools like GEANT4 and ROOT, that also could benefit from re-use of CAD-geometry.

IT infrastructure

The desktop computing infrastructure at CERN in the years towards completion of LHC consists of Intel-based PC's with Windows2000/XP or Linux operating systems. Certain servers and other dedicated services runs SUN Solaris or other Unix operating systems, but there has been a strong drive to reduce diversity in terms of supported computer platforms and operating systems. Physics computing is Linux based, with some use of MAC OS 10, while most Engineering workstations used for CAD are no longer different from normal user's Windows PC's, with the exception of big screens and high-performance graphics cards for power users doing integration studies etc. The evolution of hardware is difficult to predict, but one can expect that more engineering packages will be available on Linux and of course on future market-leading operating systems from Microsoft.

CAD data exchange

Exchange of geometry between CERN and contractors is based on 2D drawings in HPGL format with additional exchange of CAD-neutral files of 1990's quality level between EUCLID and other CAD-systems. Few CERN partners and suppliers have EUCLID and as the system is at the end of it's lifetime, subcontractors across CERN's member states are not going to invest in EUCLID. The situation is different for AutoCAD, whose *.dwg* binary drawing format is a de-facto standard for drawing exchange. The lack of efficient 3D and CAD-data exchange between CERN and its suppliers is a major productivity bottleneck and leads to a lot of expensive redesign that is error-prone and may lead to quality problems.

The state of CAD-data exchange today in industry is vastly better than 10 years ago, although not painless. The STEP standard allows for exchange and archiving of 3D solids and geometry, but most models exchanged via STEP loose their creation history and are relatively difficult to modify in a receiving system. Alternatives are the de-facto standards of common CAD-kernels such as ACIS (.sat format) or ParaSolid or direct interfaces.

Industrial companies equipped with CAD-systems such as CatiaV5, SolidWorks, Pro/ENGINEER, Unigraphics or Autodesk Inventor are able to work on shared 3D product models and collaborative design[3]. Modern CAD-systems have increasingly better CAD-exchange capabilities and incorporates tools for "healing" geometry and recognition of certain feature types from other CAD-systems. Many systems also allow for direct import of the AutoCAD *.dwg* binary format.

Regarding CAD and FEM interoperability, the principal FEM tool at CERN, Ansys can import IGES and SAT files as well as native CAD data from certain systems like CatiaV5 and Pro/Engineer. In addition there are "plugins" for Inventor, SolidWorks and Pro/Engineer that allows for direct associativity with CAD-geometry.

[3] See ProSTEP best practices and http://www.cax-if.org

Evolution of the CAD environment at CERN

Future of the CERN EUCLID installation

EUCLID3 is still a workhorse for the LHC project, but as the LHC is moving towards production and installation, the bulk of design work has already been done. In order not to disturb LHC-related activities, it makes sense to *freeze and stabilize* the EUCLID service on the current environment .

The CERN EUCLID installation is heavily customized with a number of value-added batch tools that have been developed as scripts under Unix and with the Fortran API of EUCLID. Some of these tools have been written to overcome shortcomings of EUCLID for e.g. data exchange (Consult) or data visualization (Turbo LASS), others are specifically made to assist with LHC design and integration. Although these tools provide value in the current design environment, it makes little sense to port all such specific developments to a new CAD-system. One should rather take advantage of modern CAD and PLM functionality and adapt the design processes and methodology accordingly,

AutoCAD and Inventor

Autodesk with AutoCAD, Inventor and different branch-oriented products is a major player in the CAD-market and is the first choice among small and medium-sized companies. Notably in the machine-tools- and electromechanical industry have many users of Autodesk Inventor. Attractive educational licenses also ensure that the system is widely accessible at Technical Colleges and Universities, thus well known. Furthermore there are modules for electrical engineering, civil engineering and a number of third-party applications for domains not covered by the standard Autodesk tools. Ansys is the standard structural analysis tool at CERN, with more than 40 users. Inventor is very well integrated with Ansys.

CatiaV5

CatiaV5 is an advanced and complex CAD-system that has essentially found customers in the Automotive and Aerospace industry. (Many large installations of Catia are still using the old CatiaV4 in production.) CatiaV5 has a number of modules that integrates functions such as “Digital Mock-up”, piping, cabling, FEM analysis, kinematic simulation etc. These features are powerful and potentially very useful to CERN, however, not all of these modules are widely deployed in industry. Many companies who deploy CatiaV5 focus on surface modelling, creation of car-body structures, precise NC machining of complex surfaces etc. These activities are not a priority for CERN.

Integration studies and “Digital Mockup” where one can carry out simulation of installation scenarios is the main added value of CatiaV5 as a high end CAD-system. Already now in the pilot phase CatiaV5 has proved to be very useful for integration studies, it handles well import of 3D models originating from other CAD-systems. CatiaV5 also allows the user to switch off detailed features from the model, this simplifies simulation and analysis of 3D models within Catia as well as other programs.

Risks with CatiaV5 and "high end" CAD/CAM

Although CERN has obtained CatiaV5 at a very attractive price, the fact that CatiaV5 is an expensive high-end system targeted for complete process-chains in the Automotive industry also carries a number of risks that could lead to increased costs for CERN:

- Small and medium-sized companies cannot afford CatiaV5, thus will not have the same CAD-system as CERN.
- CERN suppliers and partner institutes do not use CatiaV5 (with the exception of French institutes who are former EUCLID customers.) Support of CatiaV5 *only* could therefore lead to a situation similar to the one with EUCLID, where few suppliers have the same CAD-system as CERN.
- Expensive training: CatiaV5 is a complex product and training of skilled designers takes more time than for mid-range products such as Inventor and SolidWorks. Furthermore contract designers with CatiaV5 are in short supply and therefore more expensive than designers trained with cheaper and more common CAD-tools.
- With the current model of out-sourced design activities, CERN risks spending a lot of money training designers, only to see them take up employment in the automotive or aerospace industry after a few months.

To address these risks, CERN needs to reconsider the current policy of outsourced design offices and build up sufficient internal competence to take full advantage of the functionality of CatiaV5. We should also prepare for a heterogeneous CAD-environment to ease data exchange with suppliers and part institutes.

Key questions for the CAD-policy at CERN

- How are the design and engineering activities at CERN likely to evolve in the future?
- Will we still have dedicated design offices producing drawings on a contract basis or carry out design tasks in the engineering teams?
- Is an integrated CAD-solution really needed for all engineering activities at CERN?
- Are we able to coordinate the use of a complex system across the organization?
- Are we better off with mainstream tools within each design discipline?

Look at current practices in the LHC experiments and among suppliers. The LHC experiments have been designed with the EUCLID CAD system and Autocad, Autodesk Mechanical Desktop (and Inventor). Also for the accelerator sector Autodesk products play an important role. Autodesk packages are also widespread among CERN suppliers, so they cannot be phased out easily. Furthermore Autodesk Inventor is very well integrated with Ansys that is the main FEM calculation tool at CERN. As complement to support of CatiaV5, Autodesk Inventor should be available CERN-wide as a lightweight CAD-system for projects where this system is more suitable than CatiaV5.

Focus on data exchange and management

Along with the introduction of the new CAD-system, a coordinated effort must be done to ensure management of 3D CAD data. CAD-users must be able to easily exchange 3D CAD assemblies with partners inside and outside CERN. Today this can easily be achieved via the Web, but it is essential that the exchanged data is under configuration control. CAD-assembly structures imply product structures and Bills of Material (BOM). These structures should be used as reference for sharing of engineering data with external suppliers over the Internet. CERN's EDMS (Eigner Axalant) is a primary candidate for this as the system is already in place. However, use of a "push-button" interface/integration to CAD would be desirable.

Recommendations

- Review the design processes for the LHC Accelerator and experiments. Design is by nature core-business to be done within project teams, not outsourced to a design-office without in-depth knowledge of the project itself.
- Concentrate deployment of CatiaV5 on integration and Digital Mockup activities where the use of a high-end system can be justfied. Tolerate use of AutoCAD 2005 and Autodesk Inventor for mechanical design in medium-sized projects where the use of these tools is more appropriate than CatiaV5.
- Apply a strict policy for which design activities different CAD-systems may be used. EUCLID should only be used for design of equipment that is part of or interfering to assemblies already designed with EUCLID and part of the LHC.
- Plan the migration of data from EUCLID to CatiaV5. All data that is stored in EUCLID that represents equipment to be installed with the LHC should be archived in STEP format as well as the format of the new CAD-system.
- Focus CAD-support on design conventions and methodology along with better control of CAD-data that is exchanged with external suppliers.
    - Review CERN design conventions and rules in order to ensure improved archiving and data exchange of 3D models in a heterogeneous environment.
    - Provide easy-to update EDMS/PDM utilities that focuses on data exchange of 3D models and assembly hierarchies.

It is essential that all data exchange with suppliers is under configuration control by the project engineer and includes 3D models when available.

References:

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