Collaborative Multi-Company, Multi-Disciplinary Jet Engine Design Process

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Economic realities result in ever increasing demands on the performance of aeronautical engines as well as on their development programs. Design evolution requires close collaboration between the engineers involved, across different disciplines, geographic sites, and organizations. Typically, each organization has its own proprietary tool suite and development processes. During the 4-year EU Framework 6 VIVACE project, a virtual enterprise collaborative framework called VEC-Hub was developed based on Share-A-Space [1], and FIPER [2]. It allows flexible addition or modification of partners and/or accommodation of tool suites. The approach demonstrates efficient support of evolving engine design for a realistic design problem in a realistic organizational setting, thereby alluding to its potential in similar high-tech design collaborations.

Aircraft engines have evolved into extremely complex high-tech systems. To comply with ever increasing environmental and economic requirements, continuous design improvement is necessary. Compounding the matter, engine design is technically challenging and costly, and cannot be achieved by one company alone. To this date, the engine manufacturer, the integrator, must collaborate tightly with its first tier suppliers, especially during the early design phases. Traditionally, this includes sending specifications, CAD- and simulation-models back and forth between the partner companies, using ground-mail, e-mail or other file sharing mechanisms. Such archaic processes are labor intensive, time consuming, and only allow for limited design iterations.

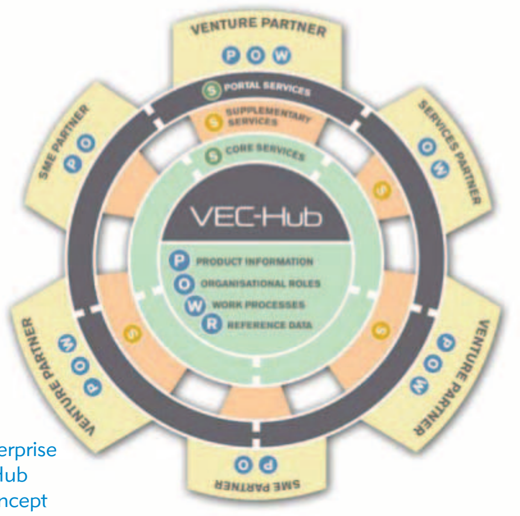


Figure 1: The Virtual Enterprise Collaboration Hub (VEC-Hub) Concept

The call for a decreased time to market dictates that these time-consuming manual tasks are substituted by a streamlined, automated design process, and for technical information to be shared, not pushed around, between the collaborating partners. This collaborative design system needs to work in an extremely heterogeneous environment, since each of the risk sharing partners will use their own, partly proprietary, tool suite. As such design tool suites are the core assets of each partner, and different engine project may comprise of different partners, the intellectual property of each partner needs to be protected when one partner needs access to, but not to have a copy of, other partners' tool suites, if such protocol is permitted.

During the course of the engine development, the design objectives will inevitably evolve, which the collaboration needs to accommodate in an agile manner. The result is the need for a multi-site, multi-company collaboration framework that allows for collaborative design process capture and iterative design optimization. The design framework used in such a virtual enterprise also needs to respond to the following challenges:

"The call for a decreased time to market dictates that time-consuming manual tasks are substituted by a streamlined, automated design process"

Data Sharing
It is essential to always know where to find approved data, and how to notify other stakeholders of changes to that data. If the data is not managed properly, configuration management and issues arising from it will consume a lot of time and resources during the life cycle of the product. By sharing data, configuration management can be managed with less effort during the full life cycle of the product, independent of which phase of the life cycle the product is in.

Work Process Sharing
As stated earlier, a mechanism needs to exist to allow for workflow integration and collaboration. Furthermore, as the development process of such complex products is highly iterative, a high degree of automation also needs to be in place for design exploration and optimization.

Intellectual Property Encapsulation
The nature of the virtual enterprise implies that the partners for one project might be competitors for another project. Therefore it is absolutely necessary that the intellectual property of each partner is not exposed to the virtual enterprise. This implies, for example, that no parametric CAD-geometry files are shared and that the local simulation based engineering workflows are totally opaque to all partners.

Access Rights and Security
The shared information needs to be secured against unauthorized access from both within the virtual enterprise and from the outside. The design system of the virtual enterprise must not jeopardize the security of the IT-infrastructure within each partner company.

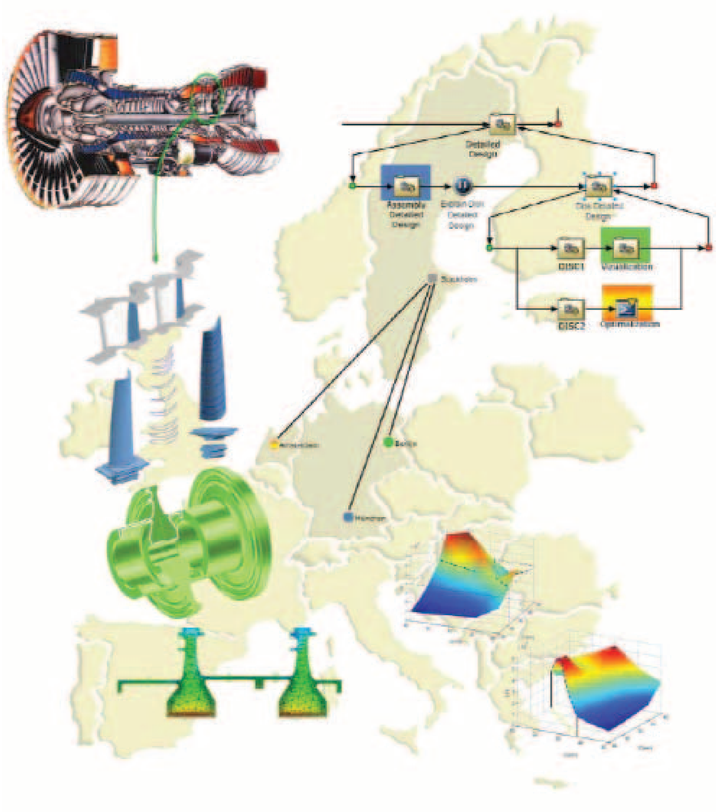
The next section describes the concept of such a design system that meets the challenges outlined above. The section after this then illustrates a first implementation of the VEC-Hub Concept for a realistic jet engine design task. While this work gives an overview of the collaborative aspects of the project, more technical details and descriptions of the local design systems can be found in ref. [3-5].

The VEC-Hub: A Concept for a Collaborative IT-Infrastructure for the Virtual Enterprise

Within the European Union Research Project VIVACE, a concept has been developed to address the needs for a multi-enterprise collaborative design system-the Virtual Enterprise Collaboration Hub [6]. The objective of the VEC-Hub, illustrated in Figure 1, is to provide a partner managed platform that is neutral with respect to technical (vendor and system), internal and external aspects.

The use of services based on platform independent application integration standards, the Web Services Description Language (WSDL), promotes, from a technical point of view, this neutrality and facilitates the use of internal partner design processes. This is achieved by only exposing the interface of these processes to the VEC-Hub whilst keeping all implementation details internal.

Figure 2: Multi-partner multi-site virtual enterprise collaboration for an engine multidisciplinary design process.



The requirement of the collaboration project is to have a common agile set-up of partner roles, product information, work processes and reference data. This information, categorized into Organizational Data (O), Product Data (P), Work Processes (W) and Reference Data (R), determines who will do what, when and how. It is stored and managed centrally on the VEC-Hub, in the light gray circle in the center of Figure 1.

The partners of the virtual enterprise can access the services which provide them with the relevant information through the VEC-Hub-Portal-Services, either using commodity tools like web browsers or application programming interfaces (APIs), if they wish to include them into their own automated local design processes.

The partners of the virtual enterprise are located at the outer circumference of the wheel in Figure 1. They can have different roles: collaborating companies that only consume services are labeled SME- small to medium enterprises. A venture partner is an entity that provides both product data and design services to the virtual enterprise and makes use of the VEC-Hub services in its internal processes.

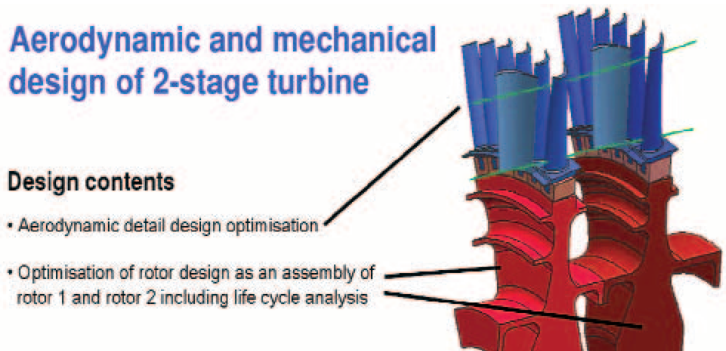


Figure 3:
Design Tasks for the High Pressure Turbine

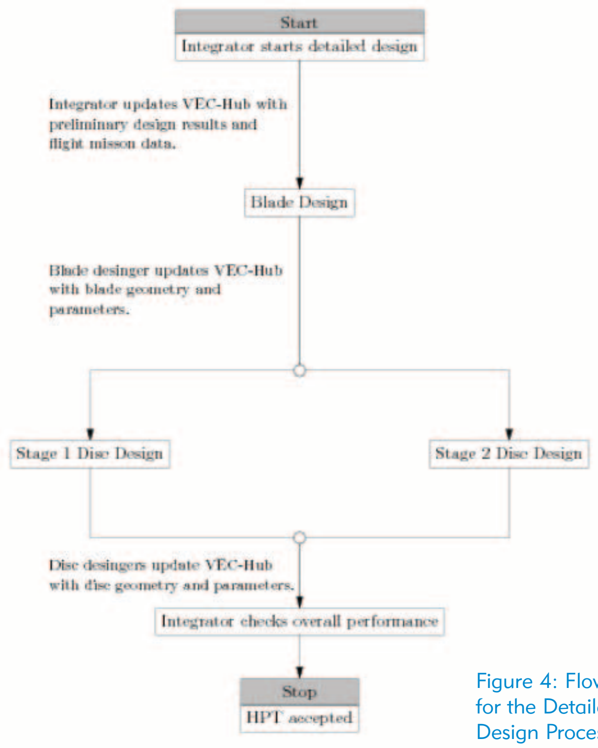


Figure 4: Flowchart for the Detailed Design Process

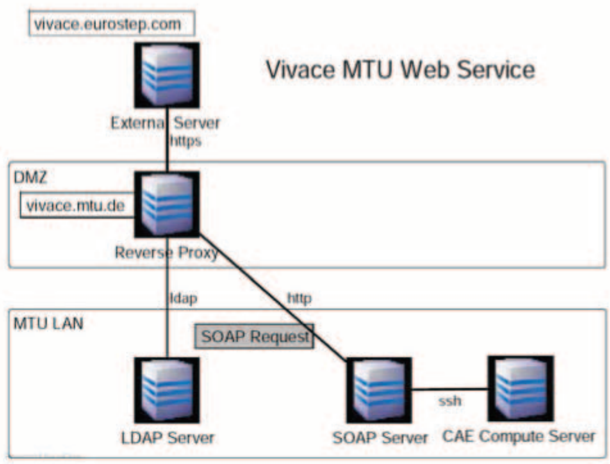


Figure 5: Airfoil Design Service Connection

Each of the organizations joining a Virtual Enterprise Collaboration have their own internal infrastructure, e.g. applications, operating systems, firewalls, security solutions. They also have means for managing their organization, their products and their processes describing how to develop those products. The Virtual Enterprise does not require the partners to align their infrastructure. Instead the shared information is made usable for each partner independent of their preferred infrastructure by using a neutral, and preferably standardized, data structure. Neutral formats support interoperability but also persistence, i.e. long- term archiving, which is important in most businesses now and for the future.

Using the VEC-Hub for Multi Company, Multi Disciplinary Engine Development Process

Within the VIVACE project, a two stage high pressure turbine of a jet engine is selected as the test bed to illustrate the benefits of applying the VEC-Hub concept. Located immediately after the combustion chamber, this assembly has to withstand extremely high gas temperatures, and is a critical part for the overall life time of the engine.

This work focuses on the detailed design phase of that assembly where four venture partners work together: the integrator, the blade designer and the disk designers for each of the two rotating blade rows. Figure 2 sketches the involved partners and their physical locations and Figure 3 gives an overview of the design tasks.

During the preliminary design phase, which is implemented with a slightly different set of risk sharing companies, but also using the VEC-Hub, the requirements for the detailed design phase are derived.
As stated in the flowchart of the detailed design process in Figure 4, the integrator starts the automated workflow by updating the shared product and flight mission data at the VEC-Hub. He accesses the VEC-Hub through the API provided by the portal services, as depicted in Figure 1.

The partner responsible for the blade uses his own in-house optimization system and exposes only the necessary interface parameters to the VEC-Hub as a Web-Service, as shown in Figure 5.

Within the local optimization system, no functionality to connect to the VEC-Hub is provided and the partner doesn't wish to implement that. Therefore in the workflow at the integrator's side, this information is retrieved from the VEC-Hub, and transmitted to the partner as parameters in the call to the exposed web service, see Figure 6.

After the geometry and the important parameters of the blades, number of blades, weight and center of gravity, have been determined, the design of the discs for each of the two stages can be started. This work is done in parallel by different partners, cf. Figure 4.

The system for designing the first disk consists of yet another set of tools, integrated within a proprietary integration framework. As with the blade optimization, it is exposed to the VEC-Hub as a web service and all necessary information is retrieved by the integrator from the VEC-Hub and communicated to the local workflow as parameters in the call to the web service. At this stage no local optimization system is implemented at the partner designing disc1, instead the design search is driven at the integrator level.

The IT-infrastructure of the partner developing disc 2 doesn't allow for a direct exposure of the local design system to the VEC-Hub as a web service. But here the local design system can make a connection to the services at the VEC-Hub and a trigger mechanism is implemented to start the local optimization task. A local loop requests a specific file from the VEC-Hub, and only starts the design task if the integrator workflow has updated this file with a specific value of one parameter. This is illustrated in Figure 8.

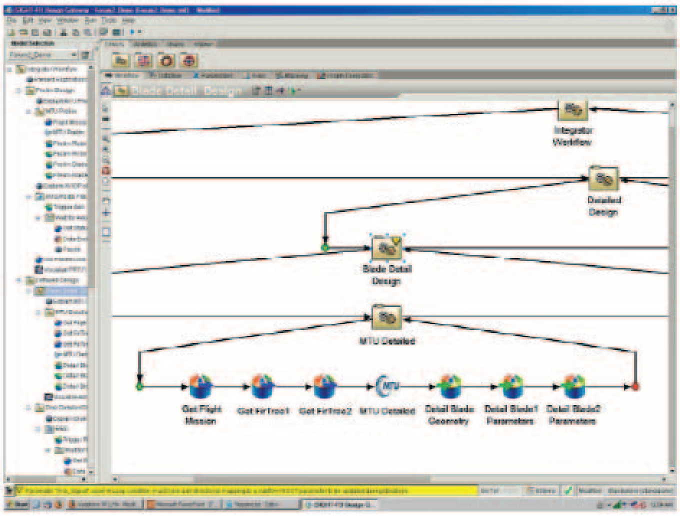


Figure 6: Detailed airfoil design process modeled in FIPER workflow. The necessary information is retrieved by the integrator in the FIPER workflow components GetFlightMisson, GetFirtree1 and GetFirtree2. After the execution of the blade optimization process in MTUDetailed, the results are shared at the VEC-Hub using the components Detail Blade Geometry, Detail Blade1 Parameters and Detail Blade2 Parameters.

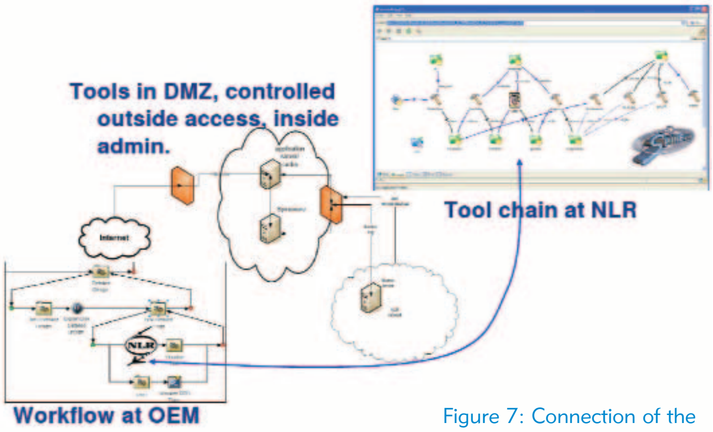


Figure 7: Connection of the Design System for Disk1

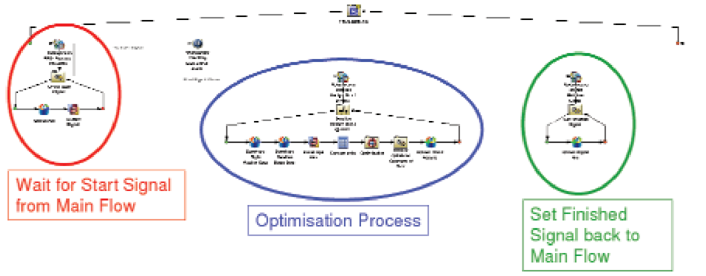


Figure 8: Design Workflow for multi-disciplinary optimization and robust design of Disc 2. Trigger-components are used for starting and finishing the local design process

After the disc design is completed, the integrator can retrieve the geometric and parametric information accessible to him from the VEC-Hub using a web browser and review the compliance, consistence and performance of the design. If this review is satisfactory, he can approve the status of the high pressure turbine on the VEC-Hub and continue with different design tasks that might now request information about that assembly.

Conclusions

Based on the organizational requirements common in aircraft engine programs, a solution has been implemented which allows many distributed partners, without one dominant partner who can prescribe the tool suite to be used, to collaborate in the design of a critical engine component. The resulting integrated design capability supports the flow of technical design information without infringing the intellectual property of the collaborating partners. The chosen realization of the tool chain with FIPER [2] allows flexible addition or modification partners and/or proprietary tool suites. The fully automated design capability efficiently supports the numerous design changes of the evolving engine design, avoiding the need for time and effort consuming paper-based engineering change processes.

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