The VIVACE project is now achieved. I'm very proud to have been part of this success story.

Not only were VIVACE's objectives highly ambitious (contribute to halve the time to market and increase integration of the supply chain) but the partnership also involved and mobilised a wide range of European Aeronautical players: industries, universities, research institutes and Information Technology Vendors. The consortium grouped 63 partners (300 workers) from 12 countries around Europe to form a critical mass of resources and hence structure the fabric of European research with regards to collaboration.

In this book you will find a brief description of the 7 VIVACE wonders produced during the last four years: "Design Simulation solutions", "Virtual Testing solutions", "Design Optimisation solutions", "Business and Supply Chain Modelling solutions", "Knowledge Management solutions", "Decision Support solutions", "Collaboration in the Extended and Virtual Enterprise solutions".

These innovative results have been created and validated through many and varied industrial (aircraft, engine and equipment manufacturers) use cases. Associated training material has been produced and large dissemination methods were put in place to help establishment of a new state-of-the-art in the area and to influence the affected standards.

Thanks to a specific integration effort, all the VIVACE results are now visible through two major tools: the "VIVACE toolbox" and the "VIVACE catalogue". Both have been created to facilitate exploitation of our results.

VIVACE has become a household name within the European Aeronautical Industry. As project co-ordinator, I sincerely applaud and thank all the VIVACE workers who contributed to this success.

We designed together, and gained together!

The time for exploitation has come.

Philippe Homsi, VIVACE Co-ordinator, Airbus

TABLE OF CONTENT

VIVACE – Value Improvement through a Virtual Aeronautical Collaborative Enterprise

▶ BACKGROUND

The VIVACE integrated R&T project, co-ordinated by Airbus and co-funded by the European Commission, was set-up in the framework of AECMA addressing Aeronautics' Vision 2020 objectives. It was launched in January 2004 and was planned to run for 4 years. 63 companies and institutions co-operate in the project, among which there are 8 SMEs.

VIVACE has used as a start point, past experiences and results gained in concurrent engineering activities such as the European project ENHANCE (1999-2002).

▶ VIVACE OVERALL OBJECTIVES

VIVACE intends to achieve a 5% cost reduction in aircraft development and a 5% reduction of the development phase of a new aircraft design combined with a contribution to a 30% reduction in the lead-time and 50% reduction in development costs respectively for a new or derivative gas turbine engine. To achieve this overall objective, the work in VIVACE is organised around **Use Cases**, i.e. real industrial simulations of a part of the aircraft or the engine or of a development process, reflecting both the Virtual Product and the Virtual Extended Enterprise. Each of them includes on the one hand requirements for early product simulation and on the other hand requirements for distributed working methods.

▶ DESCRIPTION OF THE WORK

VIVACE comprises three technical sub-projects (see Figure 1). Two of them represent the aircraft and engine products and the third one ensures integration of component frameworks developed by the first two into an advanced concurrent engineering design framework — the VIVACE Collaborative Design Environment.

At its end, VIVACE is delivering a Virtual Product Design and Validation Platform based on a distributed concurrent engineering methodology supporting the Virtual Enterprise.

1. VIRTUAL AIRCRAFT SUB-PROJECT (LEADER: AIRBUS FRANCE)

The **Virtual Aircraft** Sub-Project revolves around the main components that constitute an aircraft and has six integrated technical work packages (System Simulation, Components, Global Aircraft, Flight Physics Simulation, Complex Sub-systems, Supportability Engineering). It is designed to cover the aircraft product throughout the development life cycle (design, modelling, interfacing and testing).

2. VIRTUAL ENGINE SUB-PROJECT (LEADER: ROLLS-ROYCE PLC)

The **Virtual Engine** Sub-Project consists of five integrated technical work packages performing fundamental research to provide capabilities for a competitive European jet engine industry working across extended enterprises (Extended Jet Engine Enterprise Scenario, Life Cycle

Modelling within the Virtual Engine Enterprise, Whole Engine Development, European Cycle Program, Supply Chain Manufacturing Workflow Simulation). It has developed the different engine modules of the aircraft propulsion system and key areas of multi-disciplinary optimisation, knowledge management and collaborative enterprises.

3. ADVANCED CAPABILITIES SUB-PROJECT (LEADER: CRC-F)

The **Advanced Capabilities** Sub-Project is a key integrating work area that develops common tools, methodologies and guidelines. It consists of six technical work packages that provide cohesion between the first two sub-projects through activities that are generic and common to both (Knowledge Enabled Engineering, Multi-Disciplinary Design and Optimisation, Design to Decision Objectives, Engineering Data Management, Distributed Information Systems Infrastructure for Large Enterprise, Collaboration Hub for Heterogeneous Enterprises).

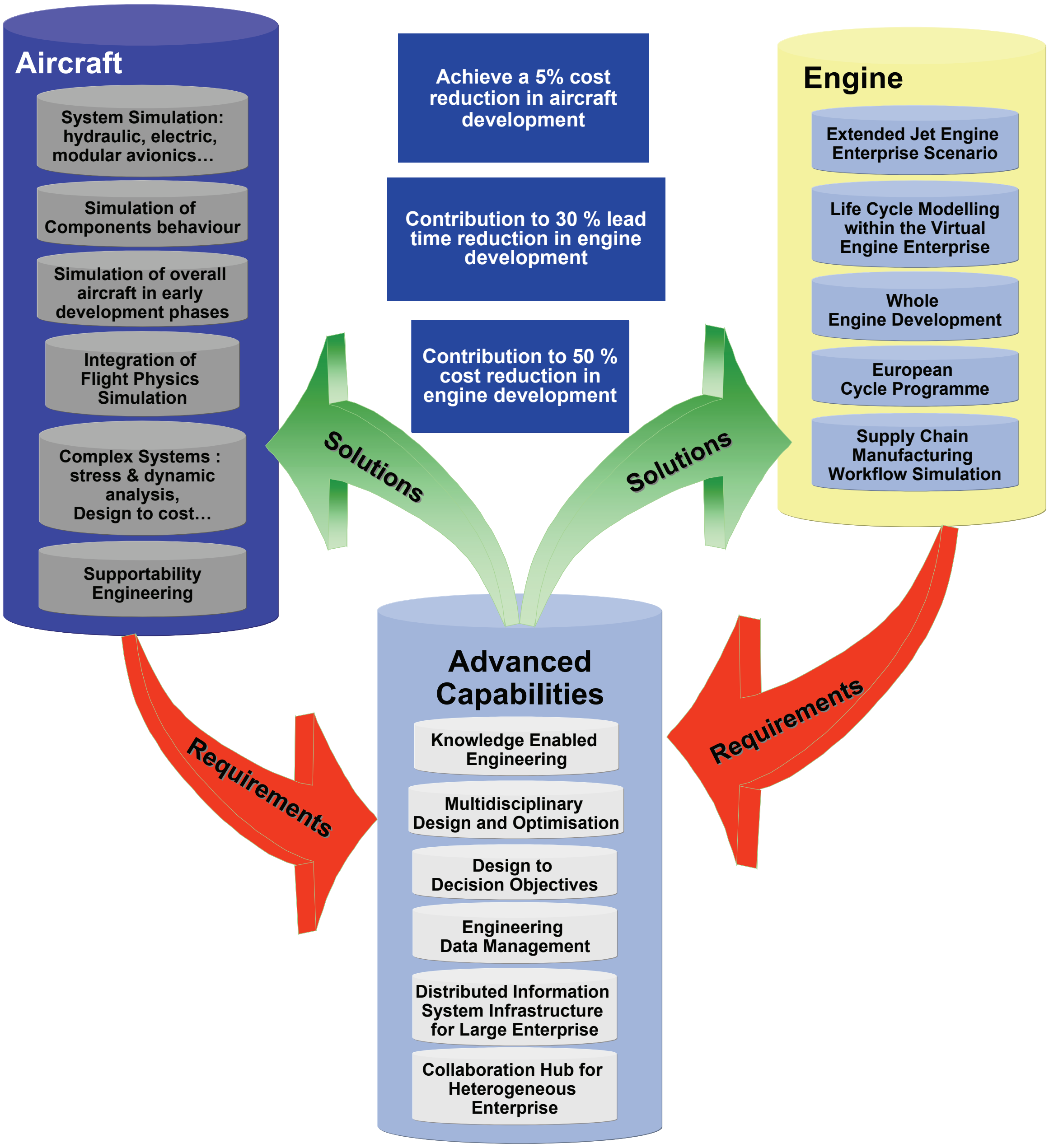


Figure 1: VIVACE overall structure

► Main achievements

The main result of VIVACE is an innovative Aeronautical Collaborative Design Environment and associated Processes, Models and Methods. This environment, validated through real industrial Use Cases, will help to design an aircraft and its engines by providing to the aeronautics supply chain operating in an extended enterprise mode, virtual products having all the required functionalities and components for the product design phases of the aeronautics product life cycle.

The large size of VIVACE and its integrated platform structure are helping its deployment of results toward the European aeronautical supply chain and in particular toward the small and medium sized suppliers.

VIVACE is making its approach available to the aeronautics supply chain via existing networks, information dissemination, training and technology transfer actions.

All information about the VIVACE project and forthcoming VIVACE dissemination events (Forums, etc.) is available on the project public web site:

www.vivaceproject.com

DESIGN TOGETHER,

GAIN TOGETHER

The Virtual Aircraft – An Overview

From a technical perspective, VIVACE has the objective to strongly reduce the development cost of new aircraft and engines, with the delivery of a Virtual Product Design and Validation Platform based on a distributed Concurrent Engineering methodology supporting the Virtual Enterprise.

The VIVACE high level objective relevant to the Virtual Aircraft Sub-Project is to contribute to achieving a 5% cost reduction in aircraft development and a 5% reduction of the last and most expensive phase of a new aircraft design, the development phase.

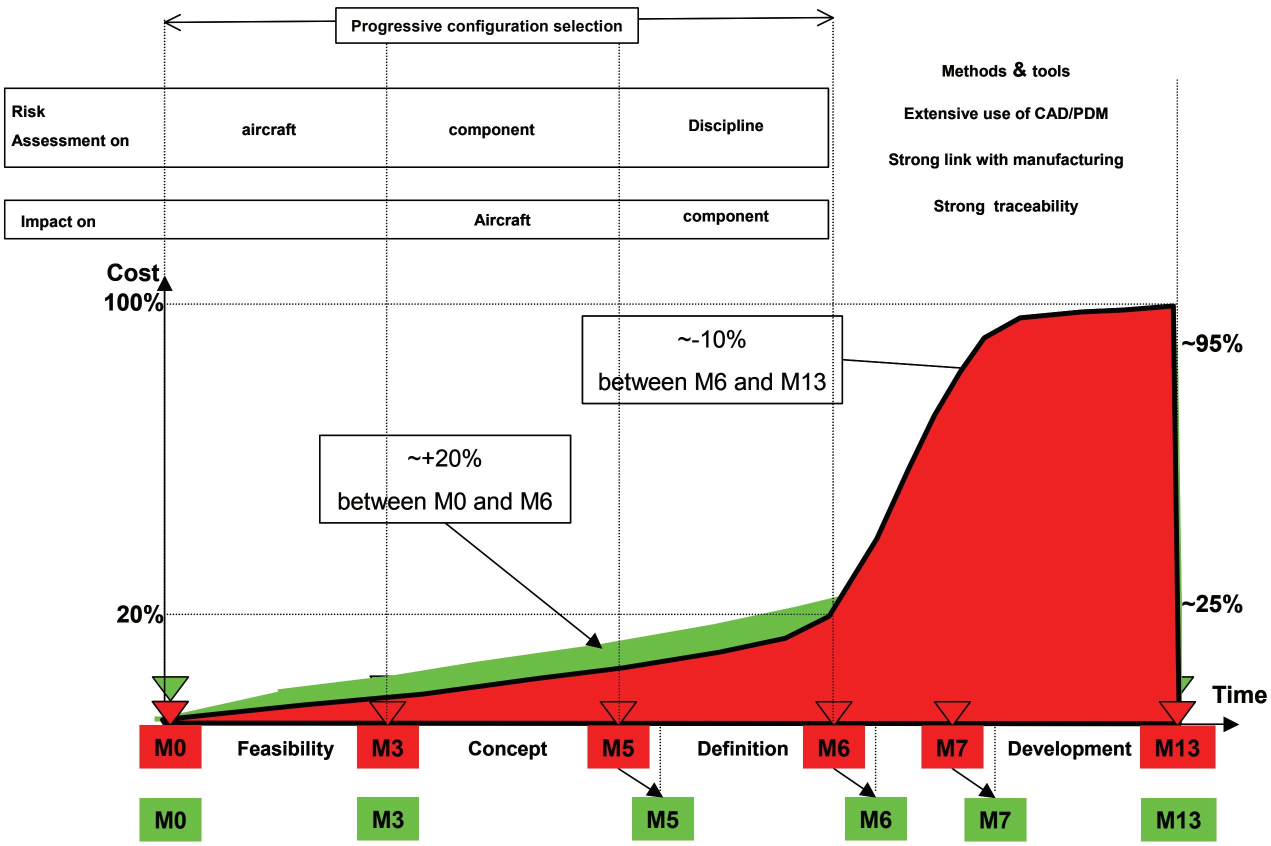


Figure 2: Proposed evolution of the aircraft development cycle

To achieve this global objective, the work in VIVACE and in particular in the Aircraft Sub-Project has been organised around **Use Cases**, i.e. real industrial simulations of a part of the aircraft or of a development process. Use Cases have been chosen to reflect both the Virtual Product and the Virtual Enterprise. Each of them includes requirements for both early product simulation and for distributed working methods.

The VIVACE Virtual Aircraft Sub-Project has been based on the following components that are described in the following chapters of this technical leaflet:

- Simulation of systems (virtual aircraft for systems, hydraulic, electric, integrated modular avionics, slats and flaps);
- Simulation of aircraft component behaviour (landing gear, fuselage, pylon and wings);
- Simulation of the global aircraft in the early phases – feasibility and concept;
- Modelling of the supportability of the global aircraft throughout its life cycle;
- Integration of flight physics simulation in the global process;
- Simulation of complex sub-systems (rotor, etc.).

These different identified components of the VIVACE system contribute to the development of a Simulation Framework in order to:

- Support the design of an aircraft as a whole in the feasibility stage;
- Enable several partners to work together on the design of a complete aircraft by sharing simulation data throughout the life cycle;
- Provide a fully distributed simulation and computation environment.

45 Use Cases have been selected from 80 at the beginning of the project to participate in the progress of the Sub-Project, starting with requirements and specifications and finishing with testing and validation of the solutions.

Solutions (elements of the Virtual Product Design and Validation Platform) to the needs expressed by the 45 Use Cases have been developed, either within the scope of the Advanced Capabilities Sub-Project, or the Aircraft Sub-Project, in terms of:

- Knowledge management
- Multi-disciplinary optimisation
- Design to decision
- Engineering data management
- Distributed infrastructure and collaborative hub for extended enterprise
- Modelling and simulation

These solutions are currently being validated and the scenarios form the basis for demonstrating the benefits. All information related to the Virtual Product Design and Validation Platform is managed in the VIVACE Toolbox (see hereafter in the Advanced Capabilities Overview section). All the results validated and assessed at a certain Technology Readiness Level (TRL) are listed in the VIVACE Results Toolbox and ready for exploitation. Over 100 results out of more than 140 have been assessed at between TRL 4 to TRL 7, demonstrated through Aircraft Sub-Project use cases and are available for further exploitation. These results can be brought to TRL 7 by partners for internal prototyping and further deployment, or may already be ready for deployment.

Systems Simulation

The goal of the "Systems Simulation" work package is to improve the efficiency of aircraft systems design, integration and certification by using simulation widely.

Improving efficiency means not only reducing effort and the development cycle time, but also improving aircraft maturity at entry into service through a better validation of inter-systems integration at aircraft level from the early stages of design.

This work package comprises five tasks including:

- One task called "Virtual Aircraft" focused on collaborative work and multi-systems integration through simulations of the virtual architecture of the aircraft systems throughout the development cycle;
- Four tasks focused on improving the design and development process of specific systems:
- One task called "Hydraulic System" dedicated to improving the hydraulic system design by using new or improved simulation models;
- One task called "Electrical System" dedicated to improving electrical modelling methods and standardising electrical behaviour modelling for data emanating from other systems;
- One task called "IMA" (Integrated Modular Avionics) dedicated to improving the Aircraft Data Communication Network (ADCN) design and validation by developing an ADCN performance model;
- One task called "Flaps" dedicated to avoiding some of the tests carried out on the High Lift test bed by replacing them with simulations.

Even though the four tasks mentioned above are concentrated on specific and unique systems, the overall objective is to have them integrated into the virtual aircraft structure for two reasons:

- The first is to check that the simulation models developed in each task can fit into a global and shared virtual aircraft architecture for cross-verification and consistency;
- The second is to enable a design flow based on off-line simulation (data and models) and on-line (distributed) simulation at enterprise and inter-enterprise levels.

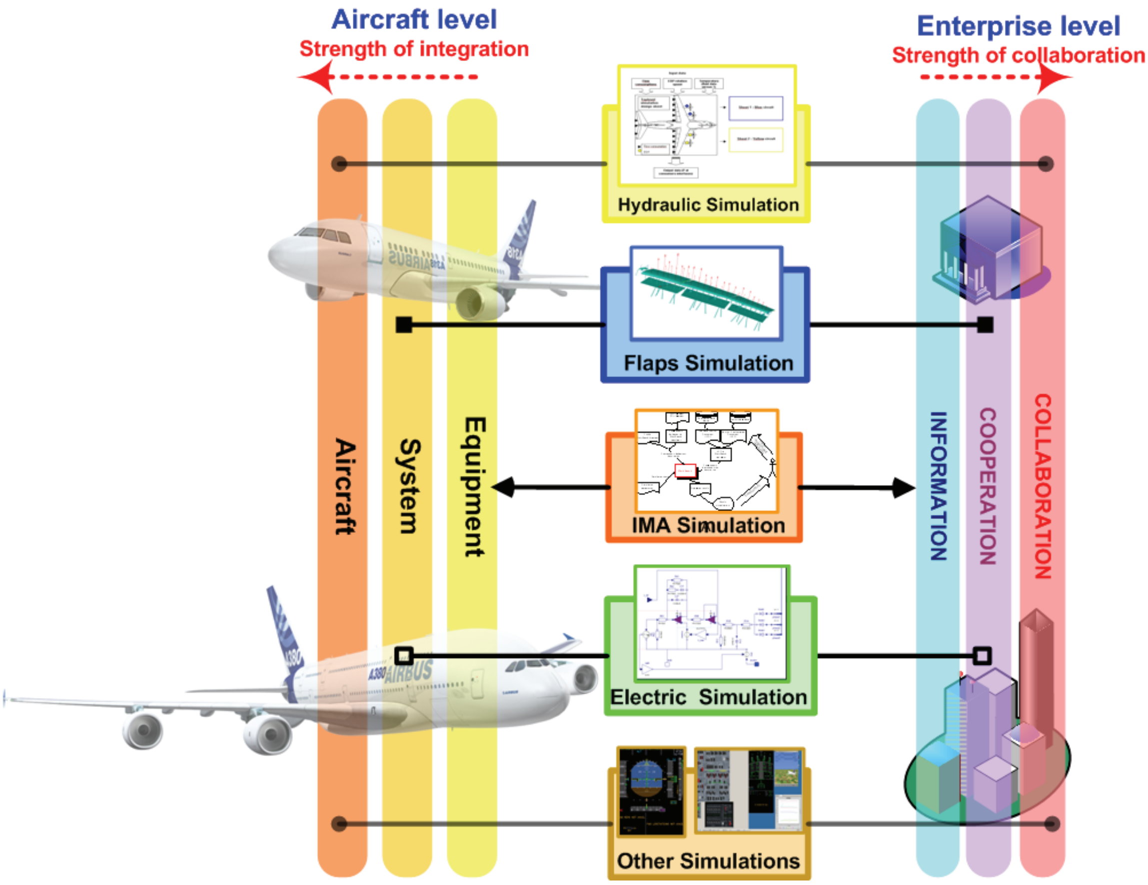


Figure 3: Integration into Virtual Aircraft

▶ Basic Description of Tasks

1. Virtual Aircraft

The Virtual Aircraft for systems will be used by an aeronautical collaborative enterprise in order to:

- Simulate the integration, verification and validation of aircraft systems as early as possible;
- Develop simulations efficiently and effectively which are fully integrated into the development process of aircraft systems;
- Share and re-use simulation components in an extended enterprise context for cost-effective operations.

To reach these objectives, the Virtual Aircraft task has developed:

- An engineering and simulation data model that digitally describes the aircraft systems architecture and development cycle together with the relevant information required for the design and deployment of distributed simulations.
- An optimised simulator development process. This process is computer assisted through

services that allow the efficient and effective construction of simulations tailor-made to user needs and business constraints.
- The re-use of already deployed simulation components in an extended enterprise to avoid duplication and deployment costs.

Virtual Aircraft for systems then becomes a capability enabling a virtual team to build, operate and re-use complex simulations.

Starting from the capture of Verification and Validation (V&V) needs, Virtual Aircraft provides simulation architects and system designers with:

- Automated retrieval of systems architecture information
- Assisted design of simulation solutions
- Assisted analysis of deployment for distributed simulation
- Quick access to simulation of distributed infrastructure
- Enhanced management of simulation results

The scope of use of aircraft systems V&V:

- Whatever the level of V&V: from aircraft to equipment level
- Whatever the domain of investigation: functional, behavioural, performance, etc.
- Whatever the location and membership of simulation components
- Includes real time and batch simulations

The operational benefits are:

- Reduced cycle time for complex simulations due to automation in the solution design
- Reduced set up costs due to re-using simulation components
- Increased simulation quality due to the systematic exploration of the complete solution range
- Reduced operation cost due to the sharing of simulation components

2. HYDRAULIC SYSTEM

The aim of this task is to increase the level of simulation in hydraulic system design and to shorten the design cycle and reduce costs by increasing hydraulic system simulation fidelity. These objectives have been reached by working on two complementary simulation models for the hydraulic system:

- The development of a pre-design model aiming to produce more realistic test cases for the design of flight control systems and hydraulic systems earlier in the development cycle;
- The improvement of a detailed hydraulic model using the SABER tool to increase the simulated hydraulic system's intrinsic fidelity. The goal of the improvements is to anticipate and, if possible, replace some Iron Bird tests (overall hydraulic test bench in

AIRBUS) or flight tests by an accurate simulation for future aircraft programmes.

The different objectives of both models are described in the following figure.

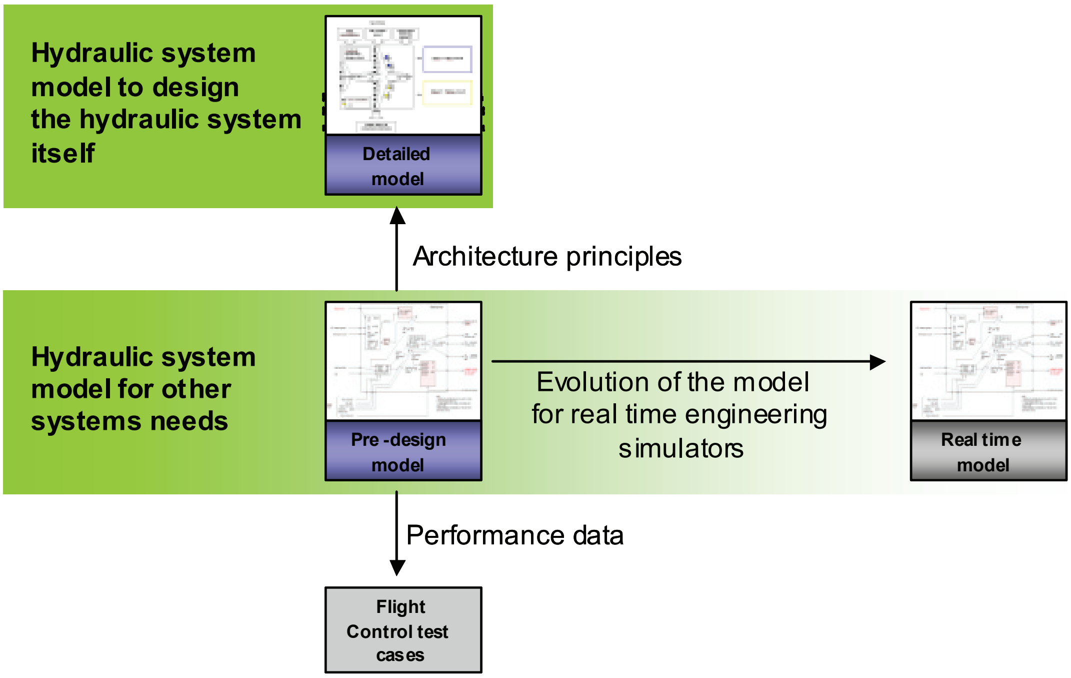


Figure 4: Objectives of hydraulic models

3. Electrical System

The aim of the electrical system task is to define methods and tools in order to improve the simulation process used for the design and validation of the aircraft electrical system.

This objective has been achieved by developing three new modelling and simulation techniques:

- A new method of multi-level modelling, which merges different modelling levels into a single model according to various needs. The main purpose of this method is to simplify the unitary testing and configuration management of electrical system sub-models delivered by suppliers;
- The definition of a "right-sized multi-domain simulation", which defines a standard method to model electrical loads provided by other aircraft systems and to speed-up the integration of the whole electrical system simulation;
- An enhanced failure modes implementation in electrical equipment models. The main purpose of this third scenario is to enlarge the models' domain of validity and improve the accuracy of simulation results in case of failure mode circumstances. To achieve this goal, new, advanced and dedicated modelling methods have been investigated, implemented and tested.

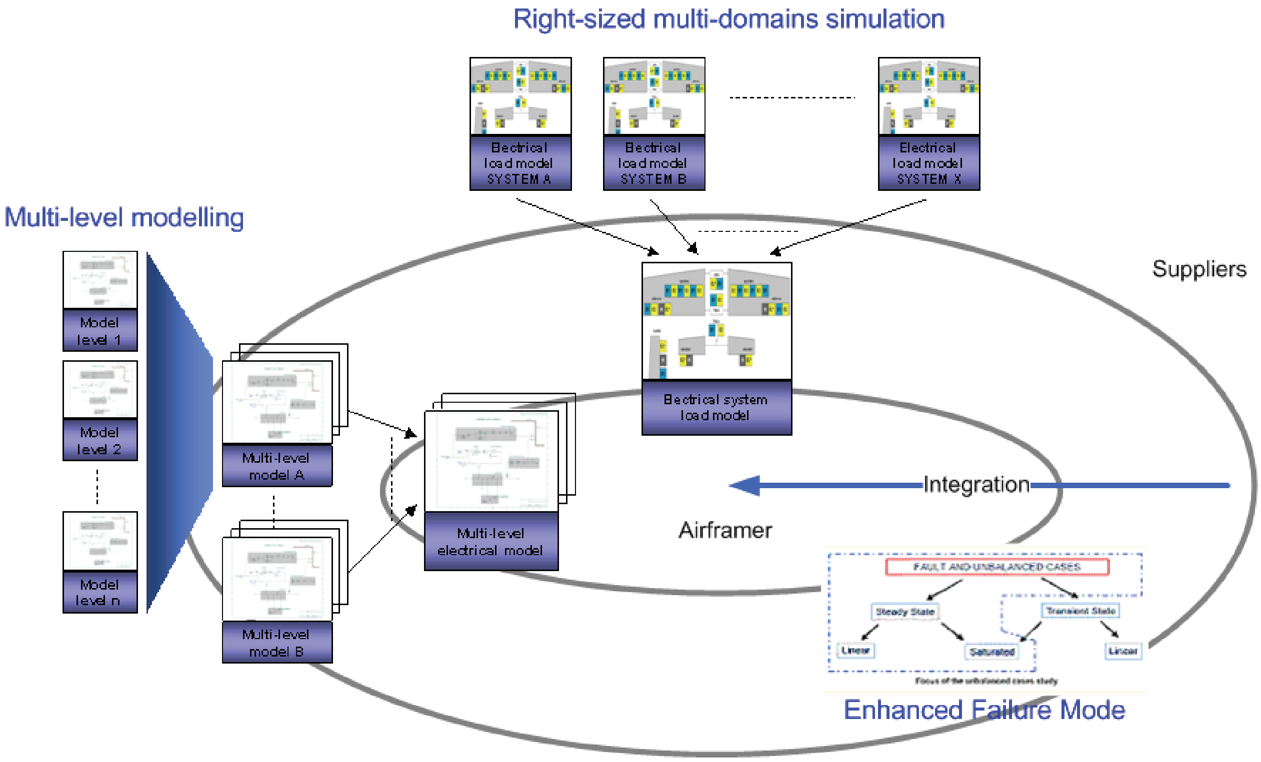


Figure 5: New methods of electrical simulation

4. INTEGRATED MODULAR AVIONICS (IMA)

The aim of the task is to re-engineer the IMA process by identifying additional simulation activities particularly in the early development phase. To assess the benefits of this approach based on the extended use of simulation, the pre-sizing problem of the SCI is treated by simulation as an example. This work is done in the context of the existing IMA developments to improve future aircraft programmes that will re-use existing IMA and ADCN components.

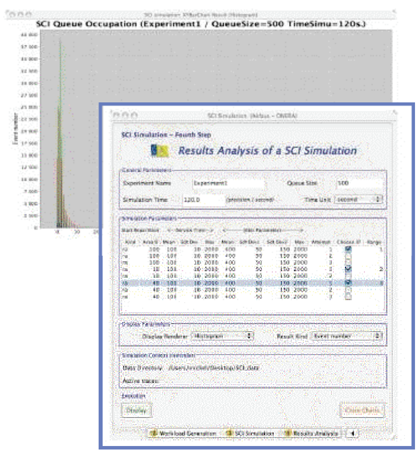


Figure 6: SCI simulation

5. Flaps

This task aims to improve the High Lift System Verification / Certification Process by partly replacing test activities with validated system and multi-body simulation. This objective has been achieved by developing a detailed high lift system model including flexible structure parts in a co-simulation environment.

For model generation, a modelling tool was developed that simplifies the modelling activities and extensively reduces modelling effort and time (Fig. 0-1). Since this tool contains predefined, verified definitions of model elements of various types, which are frequently reduced, (e.g. a model function for joint backlash or complete definitions of sub-models), the error-proneness of the modelling process is also reduced. Furthermore, experience gained in the validation process of the actual model can be used in future aircraft projects. The tool also allows easy modifications in the degree of detail of the model.

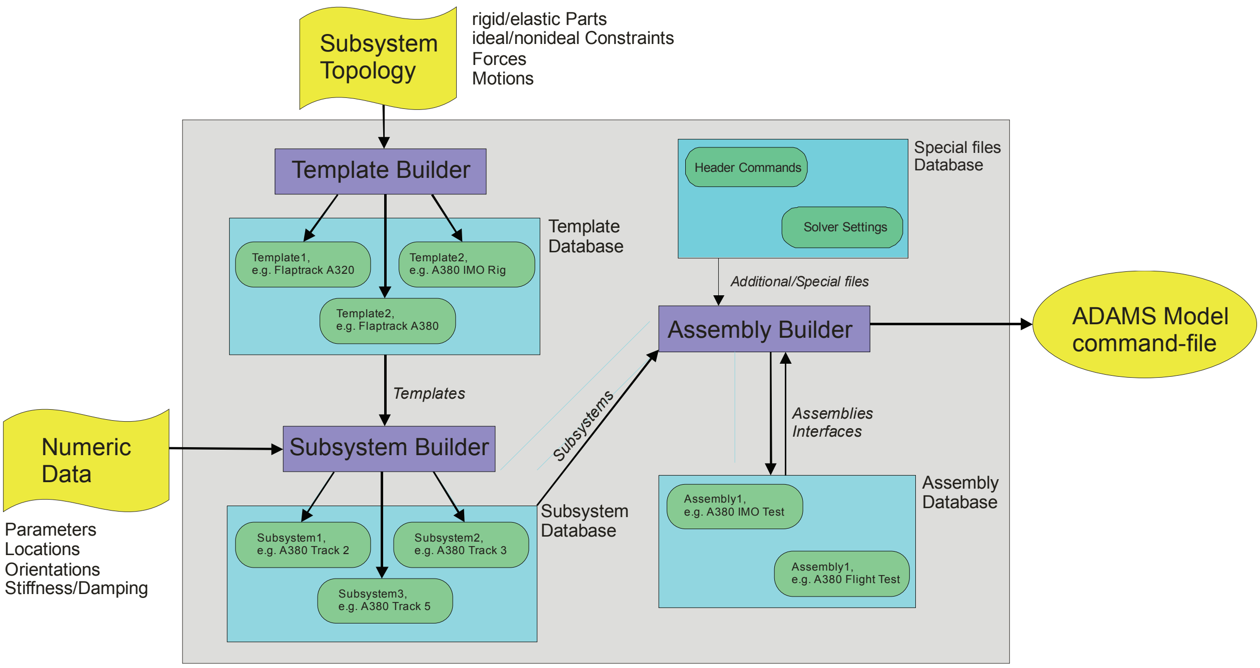


Fig. 0-1 ADAMS modelling tool

In the validation part of the project work, experience was gained on what system regions and physical effects determine the system behaviour depending on the various test conditions. The model is validated using the test results from the high lift system test rig at the Airbus Bremen facility. The model is a representation of the system test rig including the hexapod system and the pneumatically operated airload system.

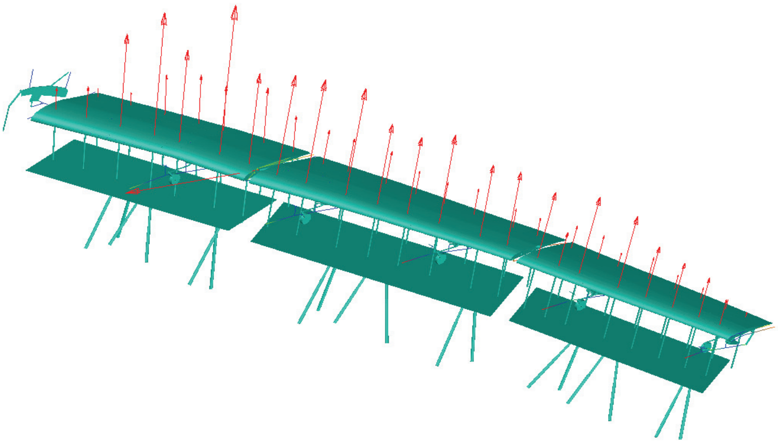


Fig. 0-2 Flaps High Lift System model

Fig. 0-3 IMO test rig at Airbus Bremen facility

The model validation was performed for a test with moving flaps (failure detection test) and a highly dynamic test (drive strut rupture test). For each kind of test, several test/simulation comparisons were made and overall, the conformity between test and simulation appeared satisfactory.

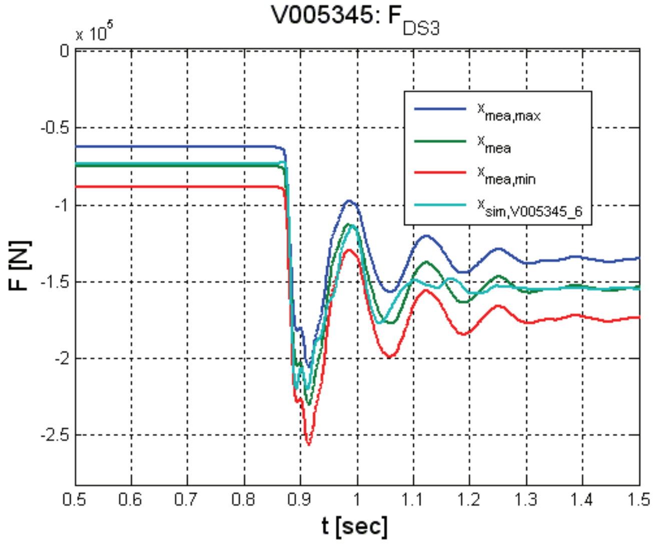


Fig. 0-4 Validation results

The integration of airloads was done with aerodynamic data from different origins and different finite element models. In addition to simple aerodynamic data from design loads documents, data from CFD-analyses can also be included directly into the model forming the basis of a MBS/CFD-co-simulation. Simple beam models for the flaps as well as highly complex fine mesh models can be included in the multi-body model. Programmes for inclusion of fine mesh models and load modelling were developed.

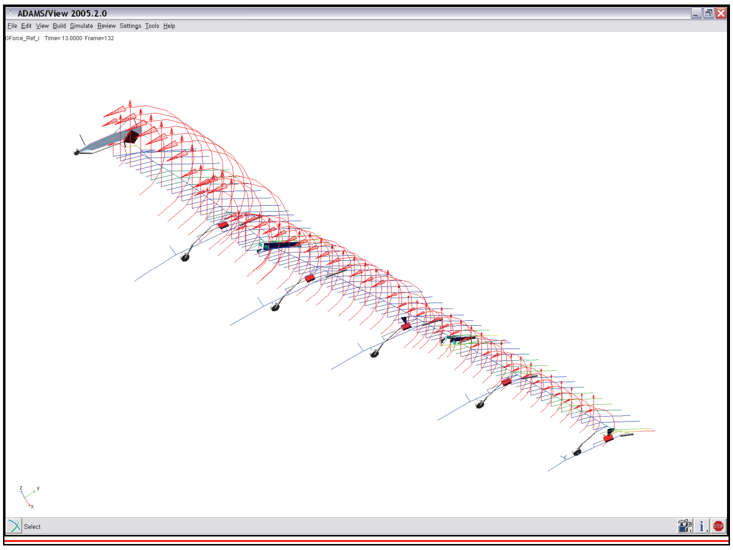


Fig. 0-5 A380 Freighter Model with realistic airload distribution

Furthermore, a co-simulation between Matlab and Adams was done. This offered the possibility to study the mechanical parts of the flap system in interaction with the Slat/Flap Control Computer (SFCC). An interface block in Simulink was developed that raised the numerical stability of the co-simulation.

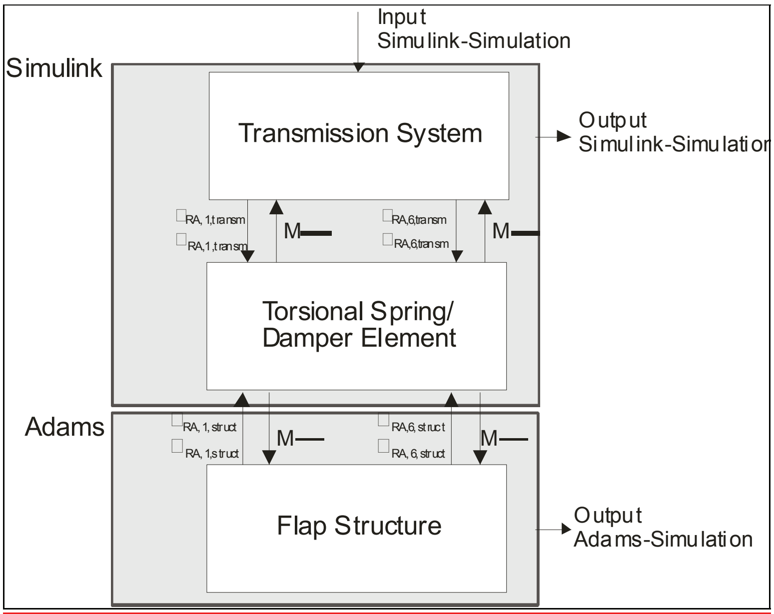


Fig. 0-6 Co-simulation interface

To summarise, the project work offers the following opportunities:

- A validated simulation of the High Lift Failure detection and Validation algorithm as a means of compliance
- Integration of models within the flight physics tasks, particularly with regard to complete flap models
- A component and system design improvement
- Improved load and aero-elastics modelling for the high lift system
- Evaluation of simulation results in a dynamic modelling environment
- System design lead-time reduction
- System validation lead-time reduction
- A flexible analysis tool with more capabilities than a test rig installation
- Short simulation times and parameterisation of complex systems such as the High Lift System.
- The capability to estimate dynamic loads in earlier development phases, long before tests are carried out, thus reducing the risk of costly redesigns after testing.
- The method developed proved its applicability by correctly predicting the dynamic loads of a design modification for the High Lift System, which will be installed in the A380.

TECHNICAL ACHIEVEMENTS

1. USE CASES AND SCENARIOS DEFINITION STATUS

All the technical achievements try to respond to typical business situations called use cases. The use cases aim to demonstrate progress from an "as-is" business situation to a "to-be" improved way of working. The current list of use cases is shown in the following figure.

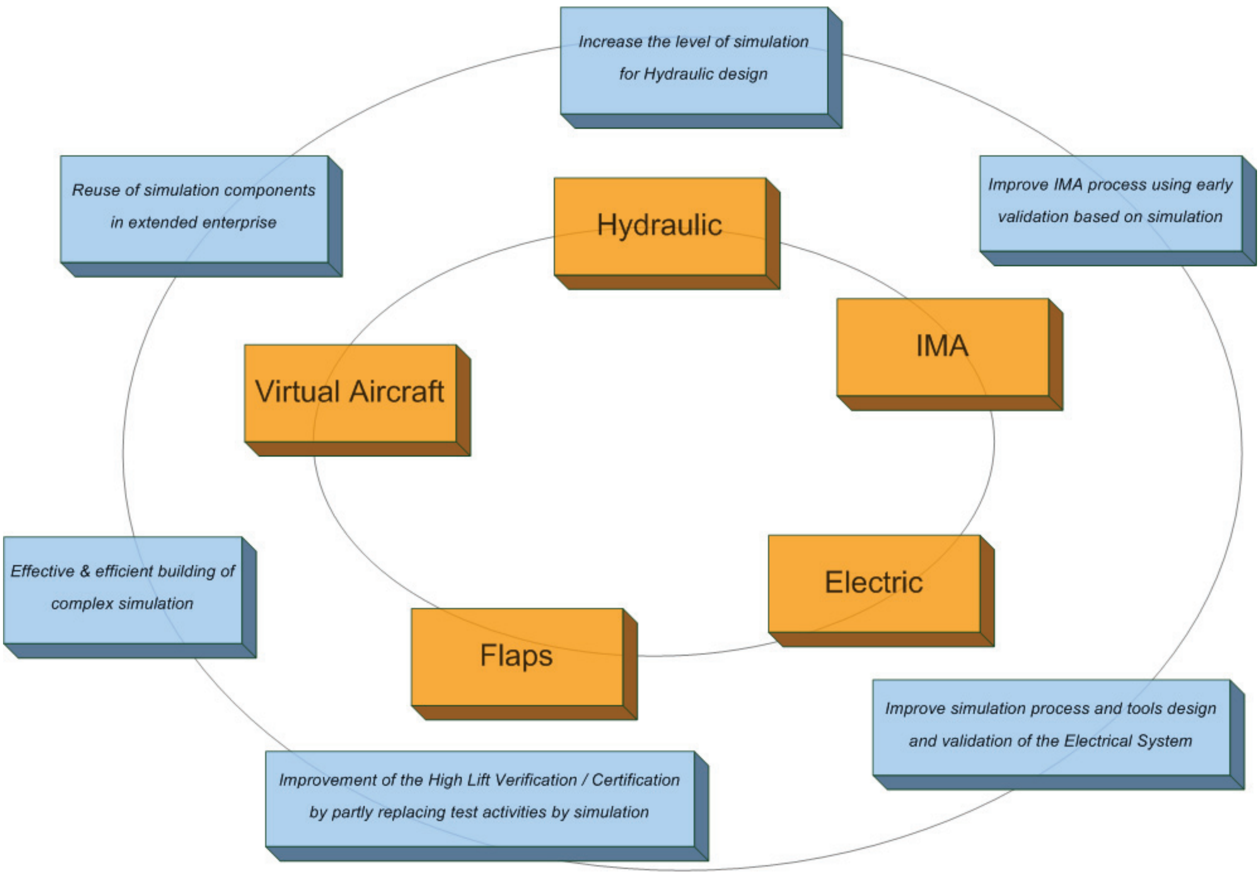
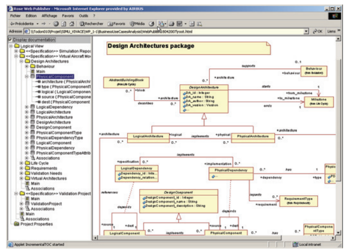
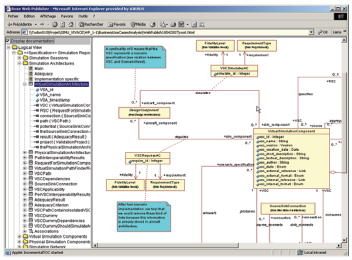
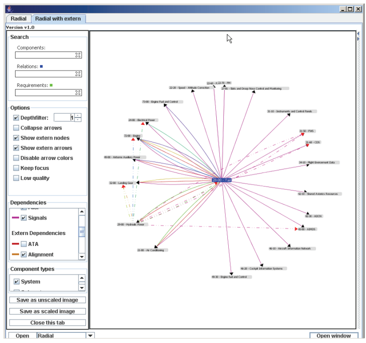
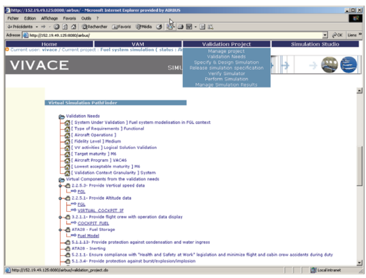
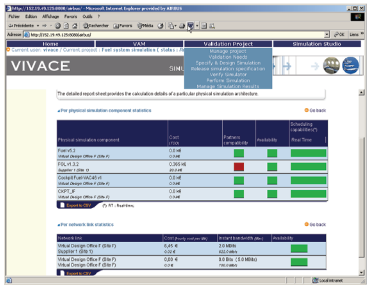
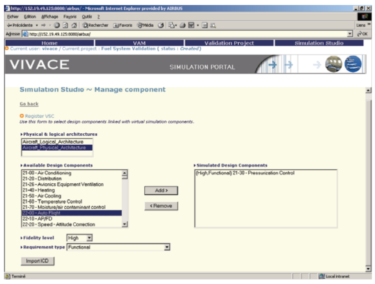
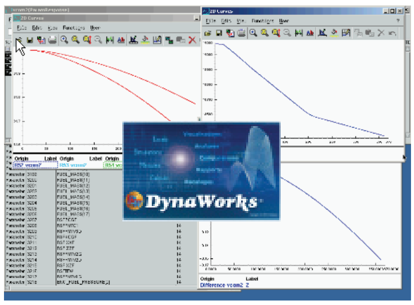
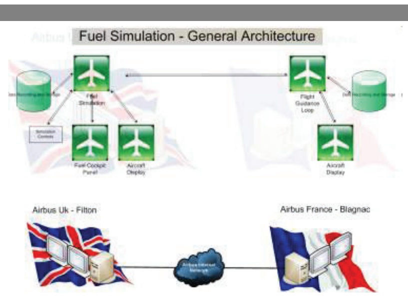


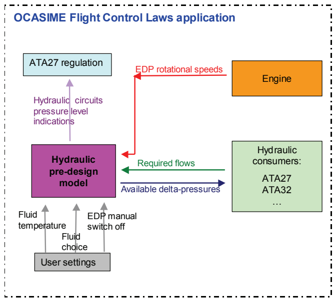
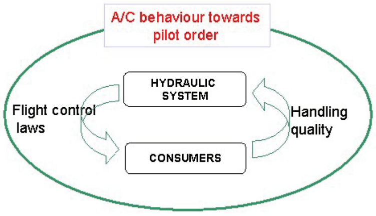
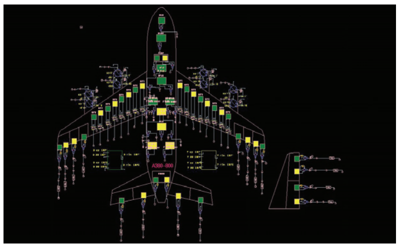
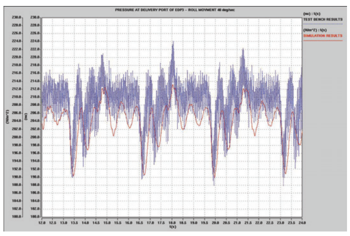
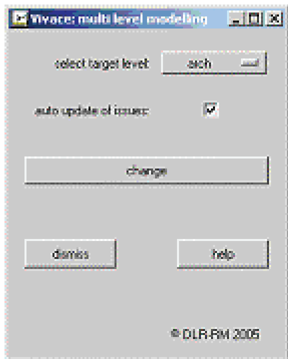
Figure 7: List of use cases

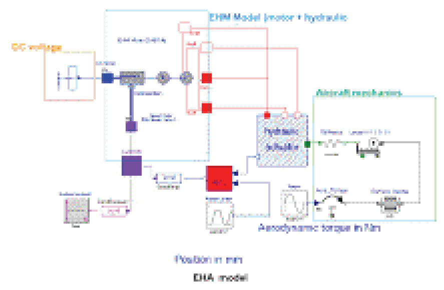
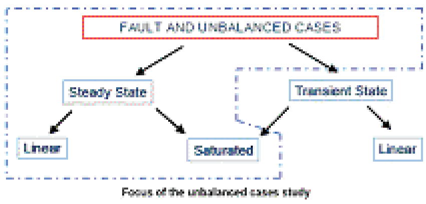
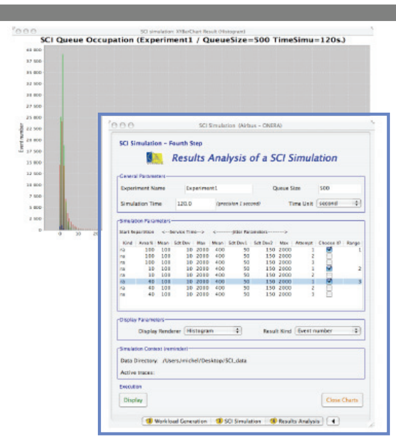
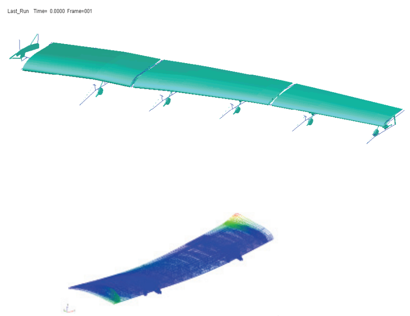
2. CURRENT ACHIEVEMENTS

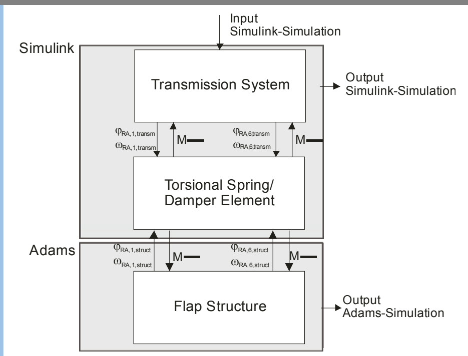
To meet the current business objectives, the following technological answers were delivered. For each of the answers presented, the associated Technology Readiness Level (TRL) is provided.

Business Objective	Technological Answer	Description	Picture	TRL
Effective & efficient building of complex simulations	***Engineering Data Model***	Coherently groups the milestones, requirements, architecture, functions, dependencies, V&V, and scenarios for systems design Living interpretation of IEEE-1471, AFIS data model and EIA 632 Used as foundation for downstream architecture activities e.g. simulation		**4**
Effective & efficient building of complex simulations	***Simulation Data Model***	Coherently groups the requirements, constraints, design and deployment information for simulation User requirements and constraints for simulation are expressed in an unambiguous way For people who want to organise simulations with “real” product structure		**4**
Effective & efficient building of complex simulations	***Virtual Aircraft Manager***	Various systems design data used to start simulation design Semantic search on architecture Advanced graphical display of aircraft architecture data enhanced with V&V contextual information Distributed as a web service to enable collaboration between remote teams Generic services towards engineering activities not specific to simulation		**4**
Effective & efficient building of complex simulations	***Simulation Assisted Design***	Automated retrieval of the relevant aircraft design information from V&V needs Intelligent services which match each part of aircraft architecture to the best corresponding simulation component Systematic exploration of all design solutions Continuous user support for best solution discrimination Distributed as a web service to enable collaboration between remote teams		**4**

Business Objective	Technological Answer	Description	Picture	TRL
Effective & efficient building of complex simulations	***Simulation Assisted Building***	Allows simulation architects to rule on the interoperability level of selected designs using semantic analysis of interface descriptions Intelligent services that analyse and propose the best deployment solution taking into account business constraints such as cost or network performance Natively designed to solve deployment issues for distributed simulation		**4**
Re-use of simulation components in extended enterprise	***Re-use Manager***	Services which manage the registration of simulation components Includes management of computing resources, networks and company membership for distributed simulation Re-uses organisation and retrieval mechanisms mapped onto "real" aircraft product organisation		**4**
Effective & efficient building of complex simulations	***Advanced Results Management***	"On the fly" acquisition of results available for high throughput real time simulations Advanced post processing facilities Native management of remote results across distributed sites Tightly linked with all the V&V projects to manage a complete simulation life cycle (SLM)		**6**
Re-use of simulation components in extended enterprise	***Wide Area Distributed Simulation***	Real time, interactive simulation for embedded systems is possible using wide area networks Advanced command & control of simulation to ease the start-up of distributed simulation Live experiment between Filton (UK) and Toulouse (Fr)		**6**

Business Objective	Technological Answer	Description	Picture	TRL
Increase the level of simulation in hydraulic design	***Hydraulic System Pre-design Model***	A real time hydraulic system model (+ principle description): - Right-sized for flight control system needs - Available in an early programme development phase - Base for more complete models Leading to: - Improvement of flight control test case fidelity - Reduction of iterations, and iteration time between a hydraulic system and flight control laws / handling quality - Earlier optimisation of hydraulic generation		**6**
Increase the level of simulation in hydraulic design	***Hydraulic Detailed Model***	Evaluated improvements on modelling principles and hypotheses taken into account for pressure drop calculation on hydraulic system network, based on analysis of Iron Bird tests on several aircraft programmes Leading to: => Improved hydraulic system model fidelity for predicting system performance and behaviour		**2**
Improve simulation process, tool design and validation of the electrical system	***Multi-level Modelling Script Simulations***	A macro allowing the use of models of different abstraction levels (architectural, functional, and behavioural) within a single "container" model. Automatically selects the desired level Allows the user to manage models that are available in different versions	AIM script interface	**6**

Business Objective	Technological Answer	Description	Picture	TRL
Improve simulation process, tool design and validation of the electrical system	***Methods for Right-sized Multi-domains***	Proposals and application of advanced modelling and simulation techniques for right-sized multi-domain simulations. Several approaches to more sophisticated modelling of components, systems and advanced numerical solvers, algorithms and computation strategies are presented. Representative test architecture for the electric power system which contains several multi-domain power consumers is defined. The methods are applied to network components in order to demonstrate possible improvements of the electrical system simulation processes.		**4**
Improve simulation process, tool design and validation of the electrical system	***Methods for Enhanced Failure Mode Implementation***	Analysis of the requirements for enlarging the simulation coverage ratio using dedicated techniques for failure modes implementation at equipment and system levels and proposing suitable methods.		**4**
Improve IMA process using early validation based on simulation	***SCI Simulation***	Simulation approach to more precisely analyse and validate the internal sizing of the Secure Communication Interface (SCI)		**5**
Improvement of the High Lift Verification / Certification by partly replacing test activities by simulation	***Structural Flap Model with Wing Bending and Real Airload Distribution***	Introduction of wing bending and realistic airloads into the MSA(ADAMS)-simulation model for simulation of mechanical failures in the aircraft flap system		**6**

Business Objective	Technological Answer	Description	Picture	TRL
Improvement of the High Lift Verification / Certification by partly replacing test activities by simulation	***Generic Multi-body Simulation with Co-simulation***	Development of a generic multi-body simulation model, implementation of a multi-body modelling tool, model validation, inclusion of fine mesh finite element models into multi-body model, model refinements, identification of relevant physical effects driving flap system dynamics, implementation of wing bending, and implementation of Adams-Simulink co-simulation		**6**

3. VIVACE Toolbox and Advanced Capabilities

The previous achievements deliver their full range of benefits when integrated with the following advanced capabilities from the VIVACE Toolbox:

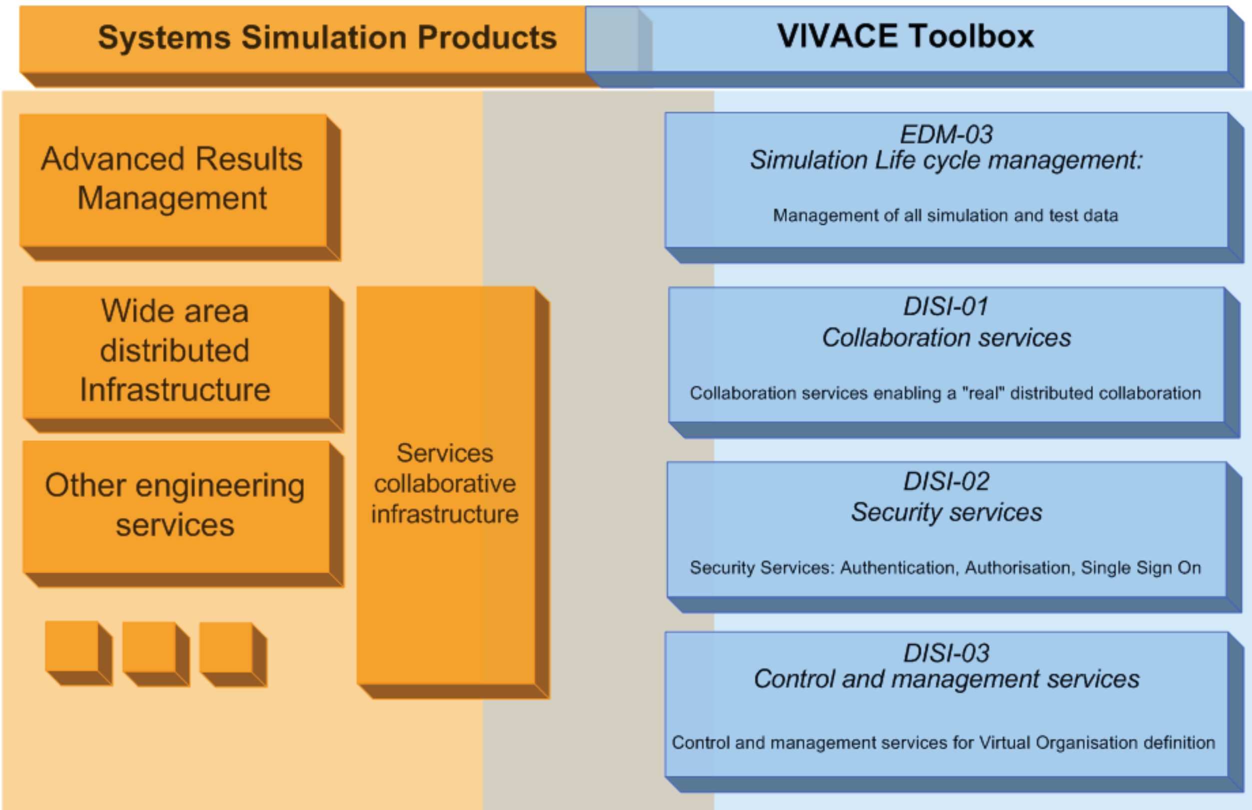


Figure 8: Systems Simulation integration within the VIVACE Toolbox

► What's Next

In the framework of VIVACE, a set of capabilities was delivered based on simulation to improve the efficiency of the systems development process.

These simulations will deliver their full added value in terms of cost reduction if they can be shared in the extended enterprise to enable a seamless design flow.

A few conditions must be met to enable the effective sharing of simulation capabilities:

- A powerful indexing system to facilitate fast and accurate retrieval of the collected simulation integrated in a complete simulation life cycle;
- Transparent and performing connections between the different actors of a development chain including security, rights management, etc.
- An unquestionable confidence in the provided simulations obtained through a rigorous verification, validation and accreditation process.

This will lead to the creation of widely employed and recognised references for simulations to be used and shared by the entire supply chain to significantly improve the development process of aircraft systems.

Aircraft Components Simulation

The aircraft components work includes 10 use cases with associated scenarios to progressively demonstrate and validate various capabilities and services developed by the VIVACE research. Figure 9 illustrates the principal orientations of the use cases with respect to the advanced capabilities. Major aircraft components (i.e. **fuselage**, **landing gear**, **wings** and **pylons**) are used as the application examples.

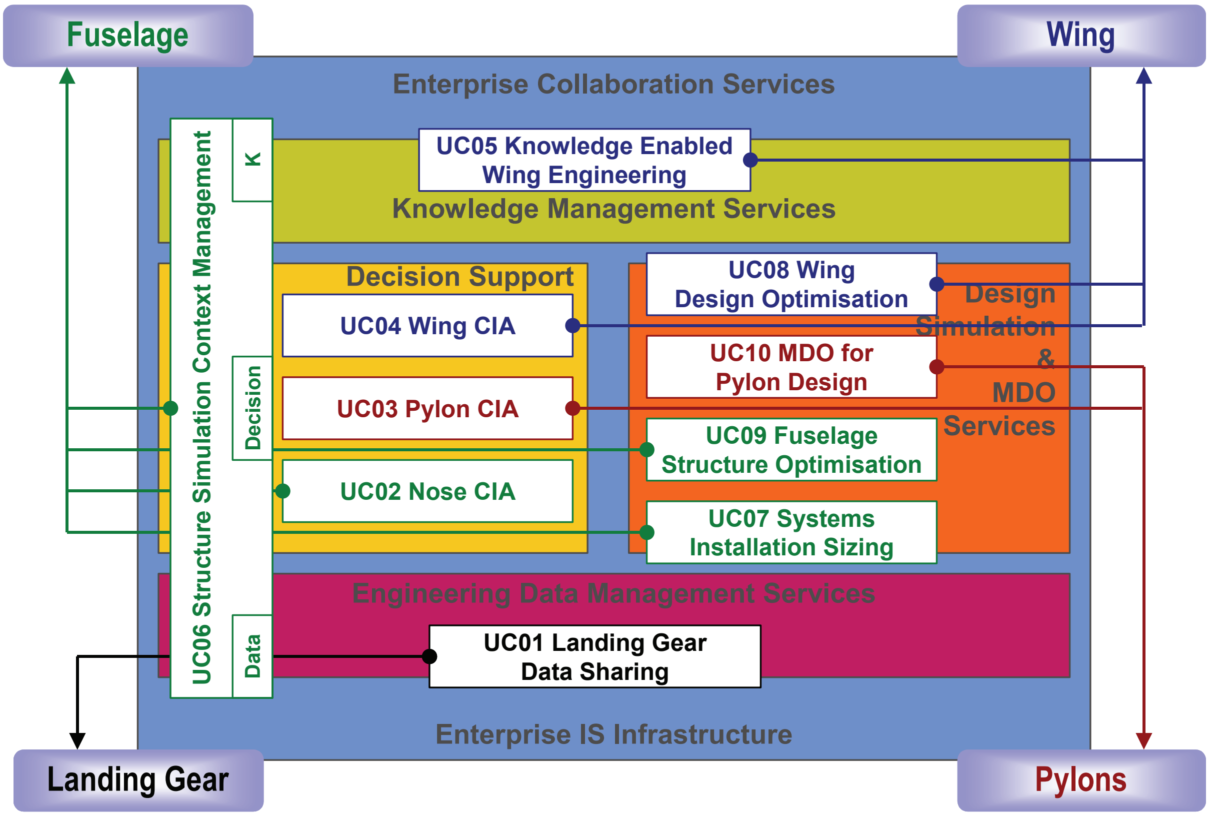


Figure 9: Aircraft Components Use Cases

The main objectives are to identify practical methodologies and innovative solutions, in order to realise the following benefits in the collaborative enterprise:

- To improve efficiency and effectiveness of **sharing data, information** and **knowledge** across the supply chain;
- To improve capture of information dependencies and the analysis of the **impact of changes**;
- To improve **multi-disciplinary design optimisation** of aircraft components.

The consortium partners directly involved in this work are Airbus and suppliers such as Alenia and Messier-Dowty, together with several technology providers and research organisations i.e. BAE Systems, CIMPA, EADS Innovation Works, Engineous, Assystem UK, NLR, ONERA, SAMTECH and Cranfield University.

The next sections outline the objectives and achievements from this work in more detail.

► LANDING GEAR DATA SHARING

The main **objective** for Landing Gear Data Sharing (LGDS) was to establish the tools and methods that will enable more rapid, efficient and secure sharing of relevant design data between landing gear supplier and airframe integrator, throughout the aircraft life-cycle.

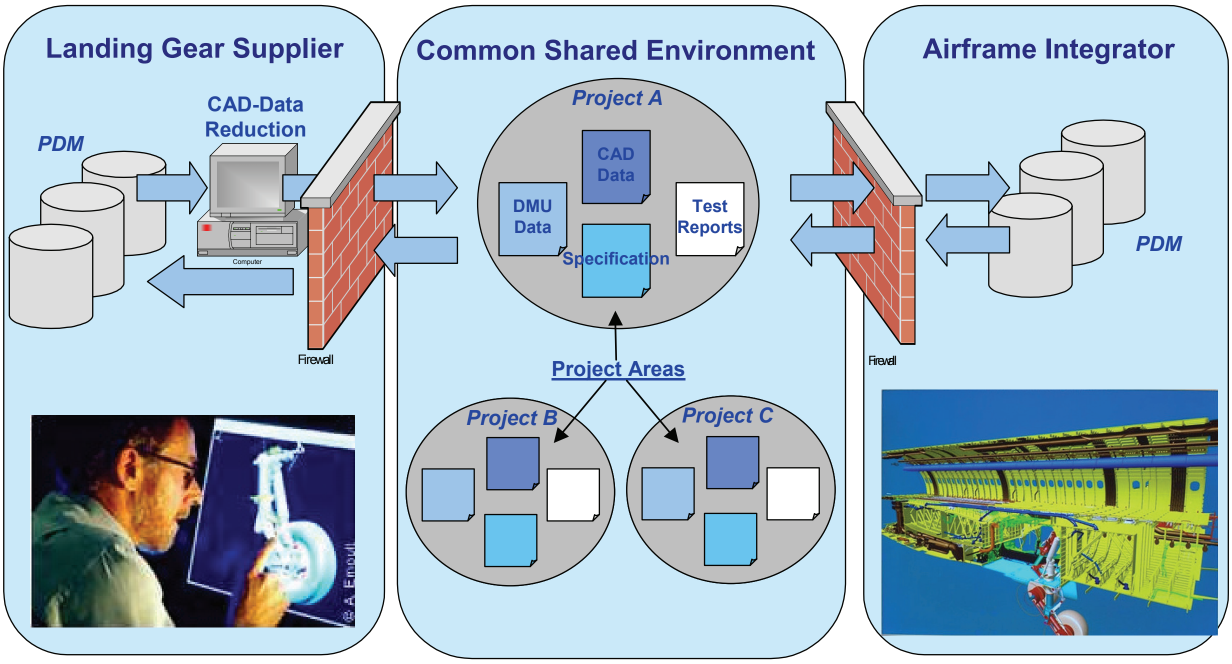


Figure 10: Proposed Landing Gear Data Sharing process

The main **achievements** are:

- A benchmark study of the 'as-is' LGDS process as seen at the start of the VIVACE project, covering the data exchanged between the two companies from the 'Authorisation to Proceed' to the 'Critical Design Review' milestones.
- A specification for a 'to-be' LGDS process using a shared environment (see Figure 10), together with a detailed description of the typical landing gear models and data that need to be shared.
- Proposed methods and preliminary demonstrators, delivered as part of the Engineering Data Management (EDM) advanced capability work, for (a) geometric data reduction and (b) a shared data environment with concurrent access for an OEM and it's suppliers including functionality for access control, product structure management, revision control, CAD integration and visualisation.

The main expected **benefits** from application of such a process are improved data traceability and significant time reductions in terms of up-to-date data release and availability.

► Change Impacts Analysis

The **objectives** for Change Impacts Analysis (CIA) were to specify a methodology and develop a supporting toolset that will facilitate decision-making in the discrimination between concept alternatives and in the engineering change process throughout the product development lifecycle.

Three major component areas were selected for the CIA use cases (nose, pylons and wing) and the capability development was carried out as part of the Design to Decision Objectives (DTDO) services.

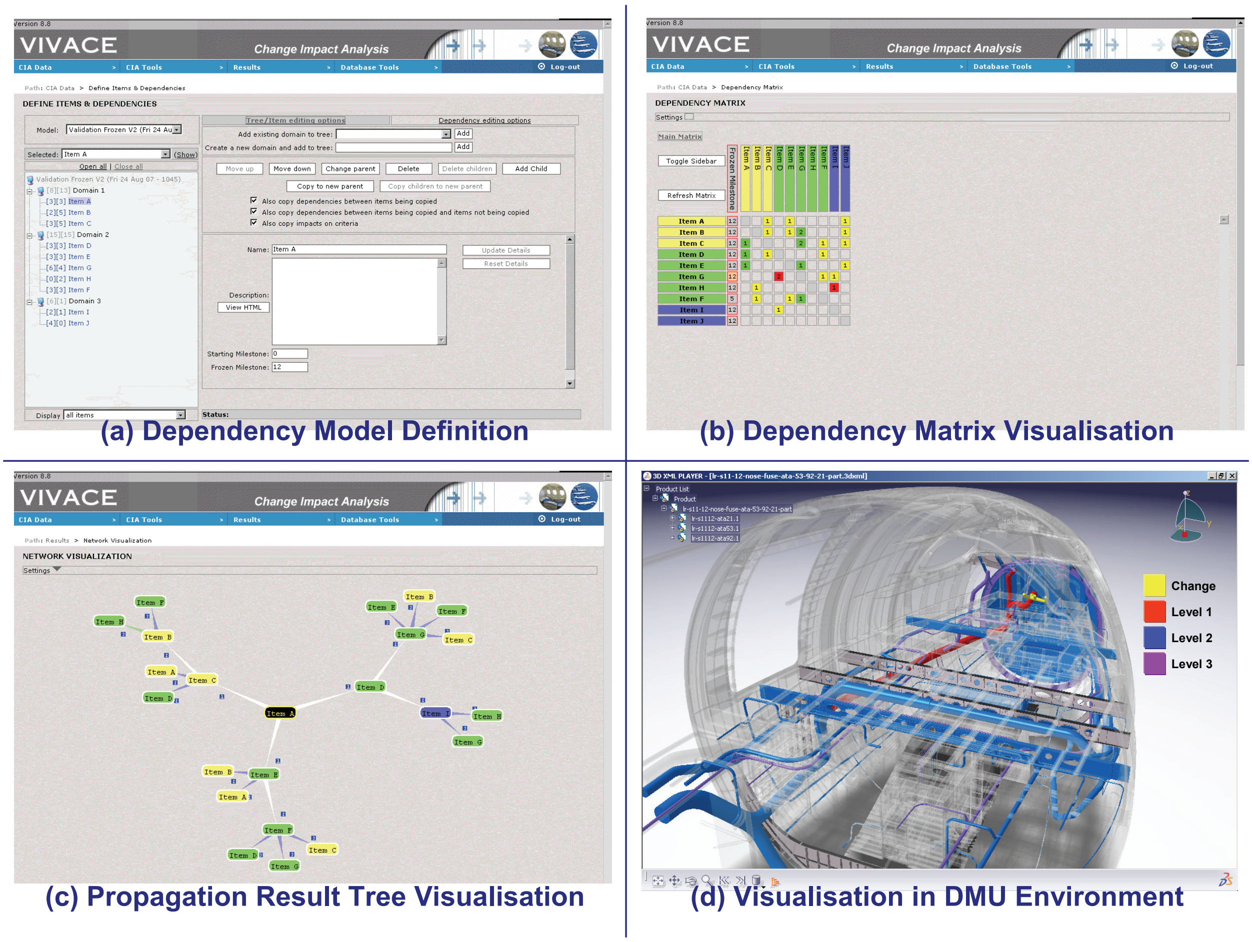


Figure 11: Examples of CIA System Functionality

The main **achievements** are:

- Documented end-user requirements and specifications to guide the development of the CIA toolset.
- The development of the CIA toolset (illustrated in Figure 11) that includes innovative modelling approaches to capture knowledge of information dependencies, to perform change propagation analysis, to provide different modes of information visualisation and to provide interfaces with digital mock-up (DMU) environments and other applications.
- A methodology to capture and validate understanding of interdependencies with the different disciplines and teams involved in complex projects and product development processes.
- Validation of the approach with Airbus use case applications and via integration studies with other VIVACE tasks and capabilities.

The CIA approach is considered to be widely applicable and the range of validation studies carried out within Airbus includes:

- Architecture behaviour analysis applications, that are considered ready to be deployed for aircraft section models.
- Specification verification applications, where maturity has reached concept demonstration.
- Technology / capability project route-mapping applications, currently being demonstrated with a number of other collaborative industrial research projects.

The results from these validation studies indicate the following expected **benefits**:

- Improved decision-making capability to anticipate the consequences of changes within complex design information and development processes. Hence, to reduce the risk of costly rework and process iterations.
- Enhancement of design validation processes, including analysis of functional behaviour compared to specifications and requirements.
- Improved capability to capture and share understanding of interdependencies between product and process information currently distributed among different teams and sites.

The next steps are to continue with wider deployment within Airbus to reach a wider spectrum of end-user applications, to further validate the approach and to identify opportunities for future functionality improvements.

► KNOWLEDGE ENABLED WING ENGINEERING

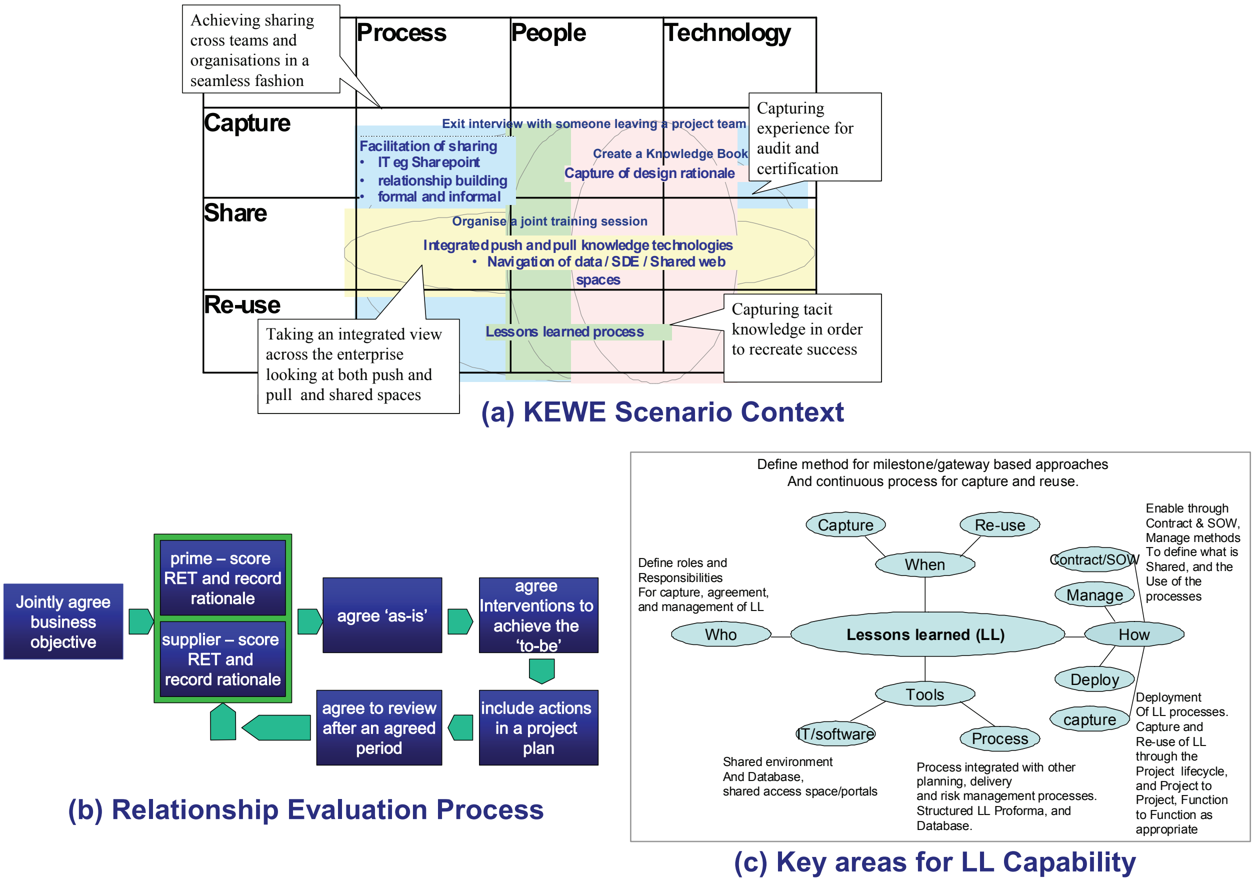
Creating or adapting product design information, negotiating and making technical or programme decisions are based upon past experience, knowledge and lessons learned. The **objectives** for Knowledge Enabled Wing Engineering (KEWE) were to research and deliver practical guidelines that will improve the sharing of knowledge across the supply chain. The vision is to provide a future environment where every participant can effectively contribute to and benefit from the shared knowledge.

The work included collaboration with the development of the Knowledge Enabled Engineering (KEE) advanced capability services, reflecting requirements expressed by the KEWE use case.

The main **achievements** are:

- The “Sharing Knowledge across the Supply Chain” scenario (see Figure 12). Knowledge challenges were validated in the context of this scenario and a detailed methodology was followed in order to generate the functional requirements.
- Documented guidelines for supply chain relationship management (see Figure 12). The expected benefits are the resolution of knowledge sharing barriers, capturing of rationale causing knowledge sharing issues, using the rationale to enhance ‘ways of working’, improving the level of trust and recognising the importance of personal relationships in supply chain teams.
- Documented guidelines for capturing and re-using lessons learned (see Figure 12). Joint manufacturer and supplier lessons learned activities will be beneficial as they lead to shared understanding, avoid the recurrence of problems and provide opportunities for more rapid improvement in future projects.

- Documented guidelines for collaborative tools to support knowledge sharing. It is anticipated that the introduction of the guidelines will result in improved access to essential information, knowledge, resources and expertise. In turn, this creates better informed teams and savings to the supply chain as a whole due to improved retrieval and re-use of knowledge.



(a) KEWE Scenario Context

(b) Relationship Evaluation Process

(c) Key areas for LL Capability

Figure 12: KEWE Scenario context and example results from Guidelines

The KEWE results are considered novel in that they support knowledge management in the context of the aerospace supply chain, whereas previous knowledge management applications tend to be focussed on individual companies.

The guidelines are considered cost effective and easy to deploy:

- They are scalable and flexible enough to be deployed in the context of any supply chain team.
- They allow capture and sharing of tacit information in the supply chain.
- They facilitate knowledge sharing through relationship building.
- They require little investment in IT infrastructure.

The KEWE guidelines are being validated with a supply chain business improvement project within Airbus, by benchmarking against existing knowledge management processes and through expert review. Further information is provided in the "Knowledge Enabled Engineering" chapter of this VIVACE technical achievements brochure. In addition, the guidelines are being made publicly available through the KEE dissemination portal.

► Structure Simulation Context Management

The main **objectives** for Structure Simulation Context Management (also known as COMPASS) were to define a methodology to map aircraft simulation and analysis processes, data, knowledge and decisions in a modular and standardised form. The methodology is considered necessary in order to design and implement an envisaged Simulation Integration Backbone (SIB) concept onto a next generation PLM system that will increase inter-disciplinary and supply chain collaboration. The establishment of an extended collaborative environment for Structures Analysis requires the introduction of new data management concepts that handle product related information in the context of the development processes, design targets and requirements.

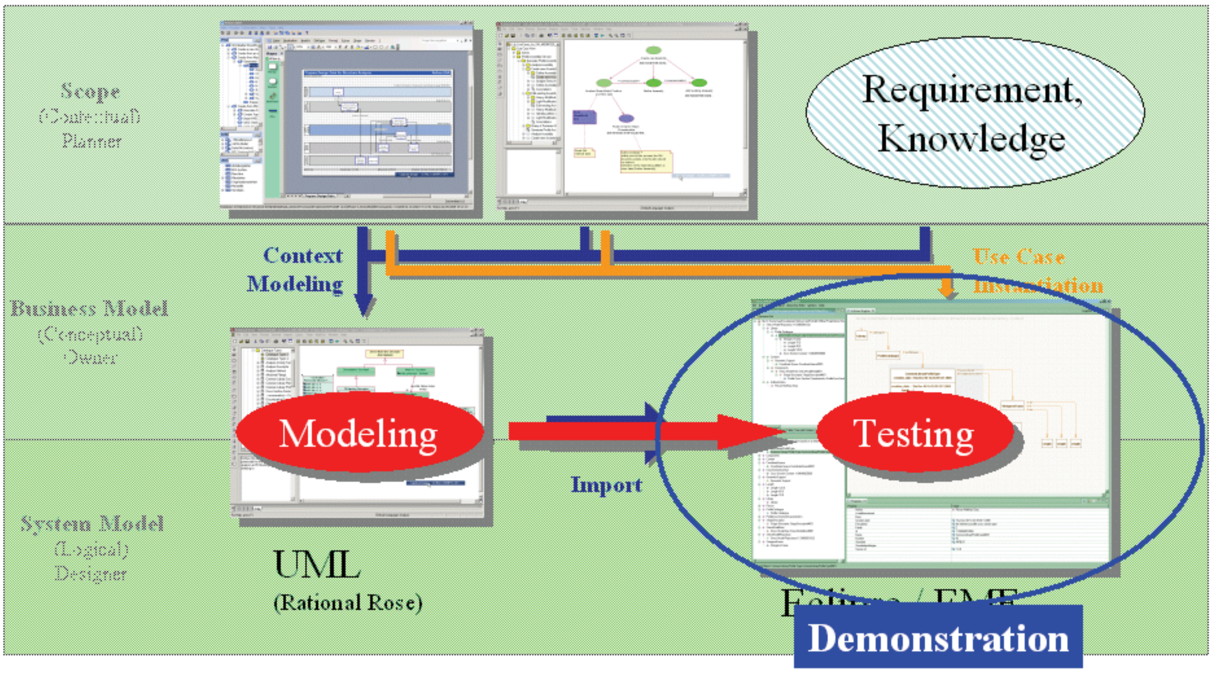


Figure 13: COMPASS Test Bench concept

The main **achievements** are:

- The Business Interpreted Model. This is an ontology and semantics based reference model that describes the dependencies and relationships between the relevant facts, requirements, knowledge, processes, decisions and data that define or impact a solution and the related processes.
- The Process Modularisation Concept. This is a semantic, scalable Process Building Block approach based on the Business Process Management Notation (BPMN®) that supports a dynamic build of request and decision driven, interlinked multi-domain integration process frameworks at runtime.
- The corresponding model based Test Bench (see Figure 13). The solutions are completed by a Model Driven Architecture (MDA®) oriented Test Bench for demonstration and validation versus use case requirements.

The development of these results involved collaboration with the KEE, DTDO and EDM advanced capabilities that are described in later chapters of this VIVACE technical achievements brochure. The generic services required to support the Business Interpreted Model include KEE services (Context-based Knowledge Search); DTDO services (Decision Information Storage) and EDM services (Information Model Builder, Information Model Navigator, Product Context Management, Consolidated Repository, Consolidated Vault). The Process Modularisation Concept is supported by the EDM 'Process Management' service.

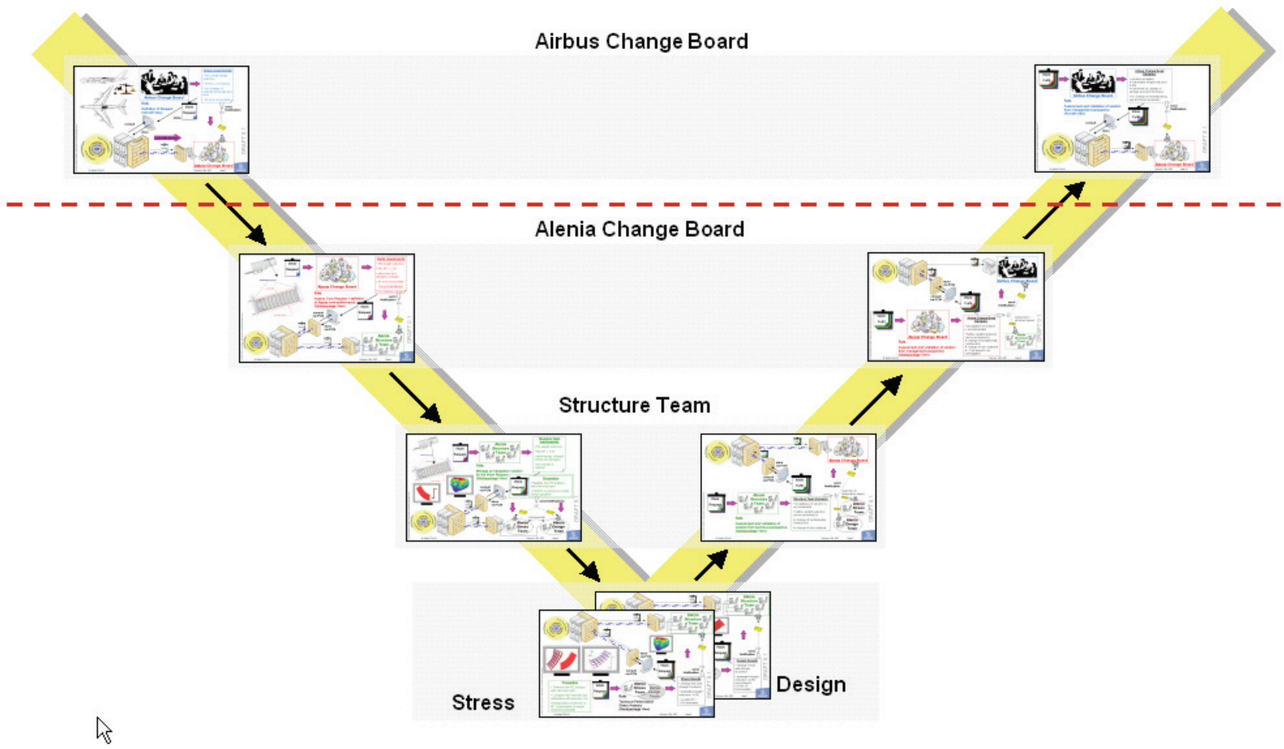


Figure 14: COMPASS 'Request for Work' Scenario

The concepts and solutions developed are validated using a representative "Request For Work" scenario, including dynamically and hierarchically nested processes with a structures engineering context (see Figure 14). This demonstrates a controlled information share between an OEM and supply chain, based on Product Context Management. Validation criteria are defined to assess the robustness and performance of the solutions, including criteria relating to storage, retrieval, search and traceability of data/information.

Thus, the main expected **benefits** are summarised as follows:

- The Business Information Model will reduce time and effort required to search for and share relevant information within the distributed development processes typically found in aircraft programmes.
- The Process Modularisation Concept will increase the visibility and traceability of multi-disciplinary integration processes and information flows.

Overall, the request and decision driven Process Management and Information Share will increase the integrity, quality and traceability of inter-domain processes and information.

► Systems Installation Sizing

Several **objectives** were considered for the Systems Installation Sizing (SIS) work: (a) to improve forecasting methods and introduce pre-sizing in systems installation design, for different disciplines (e.g. hydraulic, electrical, fuel) and at different levels (whole aircraft, section or aircraft zone); (b) to improve the design interaction loop, introduce structure requirements and implement feedback between different disciplines (e.g. reducing a pipe diameter to improve space for an electrical bundle); (c) to improve simulation functionality, to build a solution very quickly and to compare several solutions.

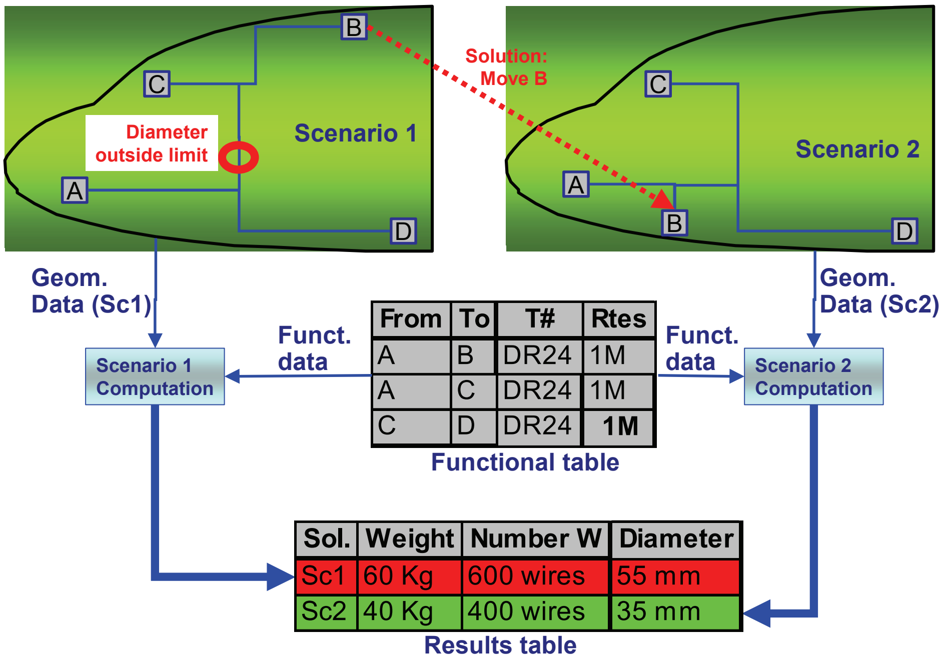


Figure 15: Electrical systems sizing comparison scenarios

The main **achievements** are:

- The definition of key indicators for each main type of systems installation considered.
- The definition of related scenarios in terms of the as-is situation, the limitations and the proposed process improvements.
- The results for optimising the size of electrical systems installations (see Figure 15), including the integration of over-braiding considerations into the electrical harnesses diameter computations and the equipped harness weight estimation. The design of an integrated process for sizing the electrical installation based on cable optimisation has also been achieved.
- The results for improving consideration of design to cost, including an analysis of materials and manpower costs for both manufacturing and installation, statistical simplifications for cost calculation with the pre-sizing data, plus a cost function for harness manufacturing.

The main **benefits** will be seen in terms of better prediction of weight savings and costs for electrical systems installations. At the end of the project, it is considered that the results have achieved sufficient maturity to be deployed for future aircraft programmes during the concept phase.

► Wing Design Optimisation

The initial **objective** was to demonstrate a multi-disciplinary engineering framework that will enable integrated wing design to evolve more rapidly and to be evaluated more consistently across all relevant disciplines. The methods should allow more efficient data transfer and a more flexible multi-disciplinary engineering process without compromising global design optimisation at the overall aircraft level.

The main **achievements** are:

- The specification of an integrated wing design framework (see Figure 16), with a parametric knowledge-based geometry generator and a preliminary process integration illustration (using FIPER). The work was continued with the 'Wing MDO' scenario by the MDO advanced capability. For further information, see the "Multi-disciplinary Design and Optimisation" chapter of this VIVACE technical achievements brochure.
- Results from application of sensitivity analysis techniques to an aerodynamic shape optimisation scenario (see Figure 17). This specific scenario included preparing (airfoil) parameterisation, definition of optimisation objectives, identification of calculation tools and schemes; constructing a surrogate model; applying variance-based methods to identify contribution of each input to the output variance and thus identifying non-significant input variables; performing robust single-objective optimisation, multi-objective optimisation and finally assessing the results.

For the results from the latter aerodynamic optimisation scenario, the main **benefits** are:

- Significant reduction in computational effort for a multi-objective optimisation problem, due to global sensitivity methods that reduce the dimensionality of the search space and hence reduce the number of calls to computationally expensive analyses.
- Improved decision making by provision of robust optimisation capability.
- Improving the trade-off analysis process in the vicinity of a candidate Pareto solution.

Although currently applied to an aerodynamic optimisation problem, it is considered that the techniques should be applicable to other disciplines and multi-disciplinary problems.

In terms of next steps, the following are suggested – investigation of the use of multi-objective genetic algorithms (to attempt to obtain better Pareto solutions); investigation of improving approximation techniques; carrying out more extensive tests on the uncertainty propagation methods (developed by Cranfield University) for robust optimisation.

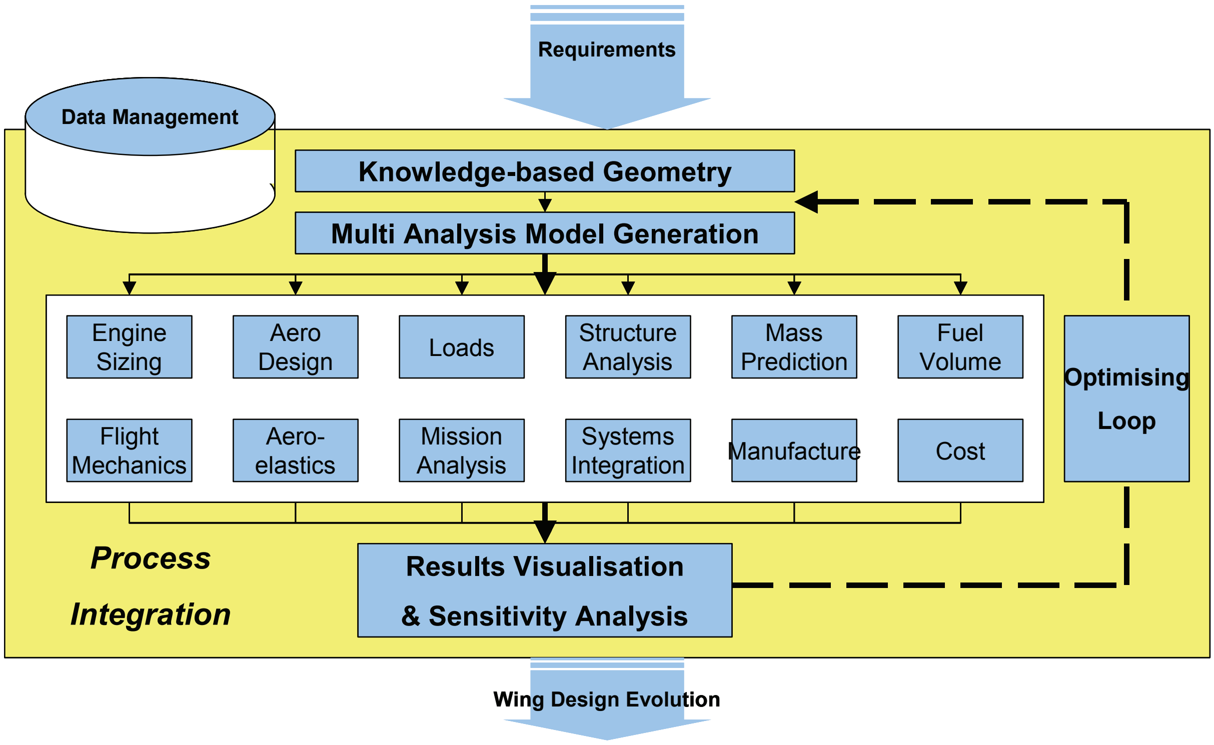
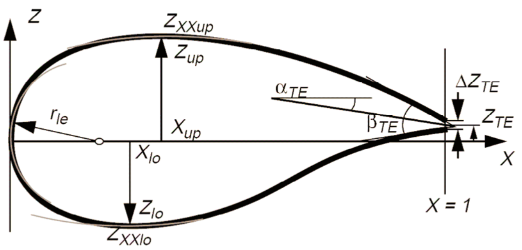
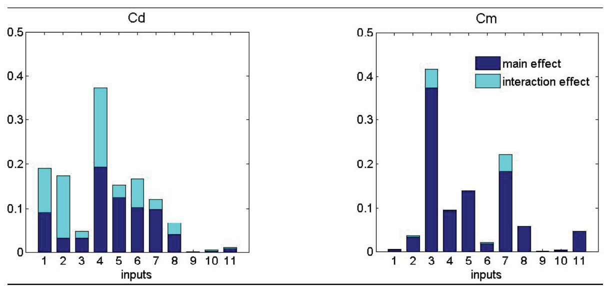


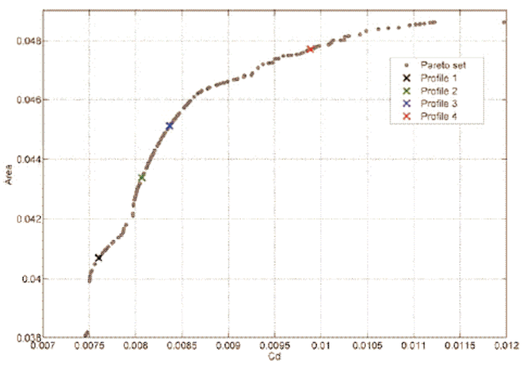
Figure 16: Multi-disciplinary Engineering Framework for Integrated Wing Design



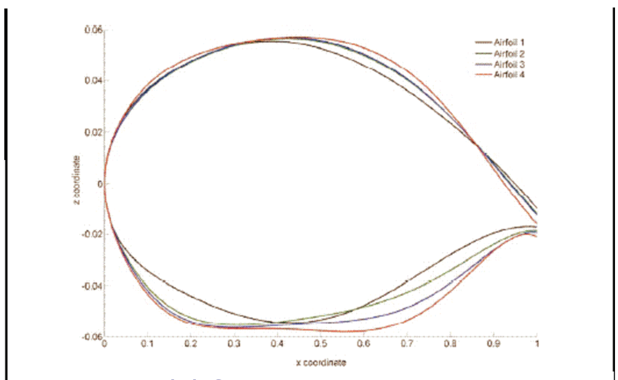
(a) Test Case Airfoil Parameterisation (PARSEC-11)



(b) Variance-based sensitivity analysis – effect for Cd and Cm



(c) Some characteristic solutions in the criterion space



(d) Some characteristic Pareto solution airfoils

Figure 17: Results from Aerodynamic Shape Optimisation Scenario

► Fuselage Structure Optimisation

The **objective** was to carry out research into structural optimisation techniques and apply these to fuselage examples, with the aim of improving stiffened panel optimisation capability.

The main **achievements** are:

- The development of a process and a framework for fuselage structure optimisation, as illustrated in Figure 18. The framework enables the integration of local structural optimisation in the global process. Improvements in the application manager capabilities of BOSS Quattro (from SAMTECH) were delivered. A rapid detailed sizing optimisation process has been demonstrated and validated for a full fuselage barrel structure (including over 1000 super-stringers). Impressive time reductions were shown using a parallel architecture (PC grid) and neural network based response surface modelling approach.
- The development of an optimisation capability applied to non-linear finite element analysis (FEA), as illustrated in Figure 19. Following the development of sensitivity analysis for the SAMCEF/MECANO solution, structural responses can now be derived in terms of geometrical non-linearity. The capability for simultaneous buckling and collapse optimisation has been demonstrated and validated for a composite stiffened panel.

Overall, these results provide robust and original methods in the field of Computational Structure Mechanics (CSM). The main **benefit** is seen in terms of process improvement and significant reduction in computational effort. Large weight savings and reduced lead-times can be expected for future aircraft projects. But, the next steps are first to further consolidate and then exploit the results in the industrial environment.

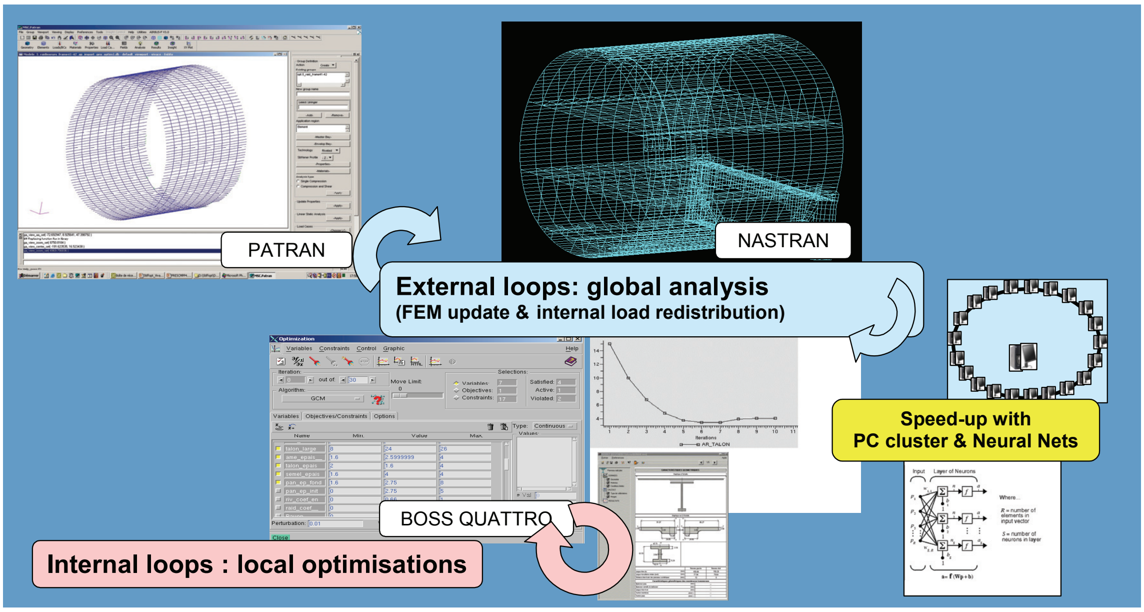


Figure 18: Framework for Fuselage Structure Optimisation

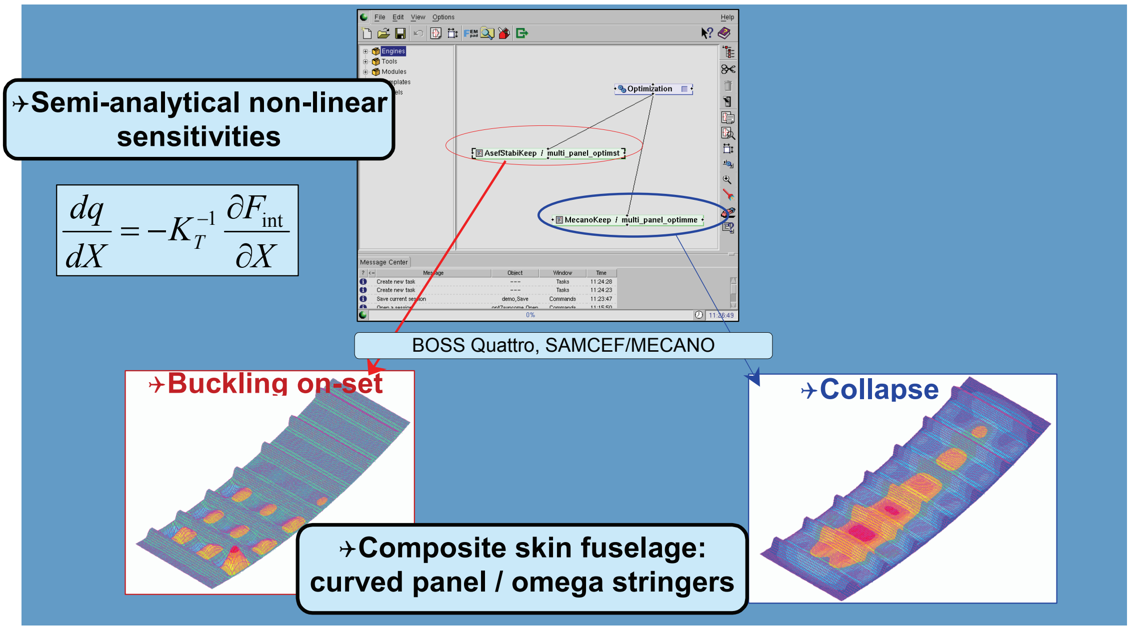


Figure 19: Local Optimisation Capability based on Non-linear FEA

► MULTI-DISCIPLINARY OPTIMISATION FOR PYLON DESIGN

The **objective** was to carry out research into multi-disciplinary optimisation techniques and apply these to pylon examples, in order to improve preliminary design with better trade-off capabilities.

Various multi-disciplinary optimisation topics have been addressed. Intentionally, the scope was limited to bi-disciplinary optimisation in order to maintain reasonable goals. The main **achievements** are:

- The development of a process for Stress and Aerodynamic optimisation, as illustrated in Figure 20. This is based on simultaneous weight and drag optimisation in a multi-level optimisation approach using direct optimisation solvers and intermediate response surface models. The results include robust adjoint methods developed for sensitivity analysis of complex CFD configurations (3D Navier-Stokes) and powerful response surface techniques (Kriging).
- The development of processes and frameworks for Stress and Loads optimisation, considering two kinds of loads. The importance of considering the sensitivities of loads to stiffness was demonstrated through direct derivation or response surface models. For a pylon sizing case, fan blade-off loads were considered (illustrated in Figure 21), as an example of specific loads linked to powerplant and based on complex non-linear simulations. For an extended wing and pylon design case, steady manoeuvre loads were considered (illustrated in Figure 22), as an example of standard loads based on flight mechanics simulations. For both kinds of loads, two scenarios have been investigated. The first scenario is based on 'classic' load loops. The second scenario is referred to as aero-elastic tailoring, because structure flexibility is used to optimise the performance (in this case, to converge to minimum weight).

Overall, the results are considered to be reasonably mature. The main **benefits** are improved optimisation of aircraft performance, from consideration of more criteria and better integration in the early design phases. For stress and aerodynamic optimisation, the results have already been used to beneficial effect on a current aircraft programme during powerplant trade-off studies. For stress and loads optimisation, the second scenario (aero-elastic tailoring) is showing benefits in terms of weight saving, compared to the first scenario (load loops).

For the next steps, it is proposed to continue towards a more complete multi-disciplinary optimisation scheme integrating stress, loads, aerodynamics, considering active control through movables and extending constraints and optimisation to the full aircraft. The increase of computational means and the use of response surfaces are considered as fundamental computer science enablers.

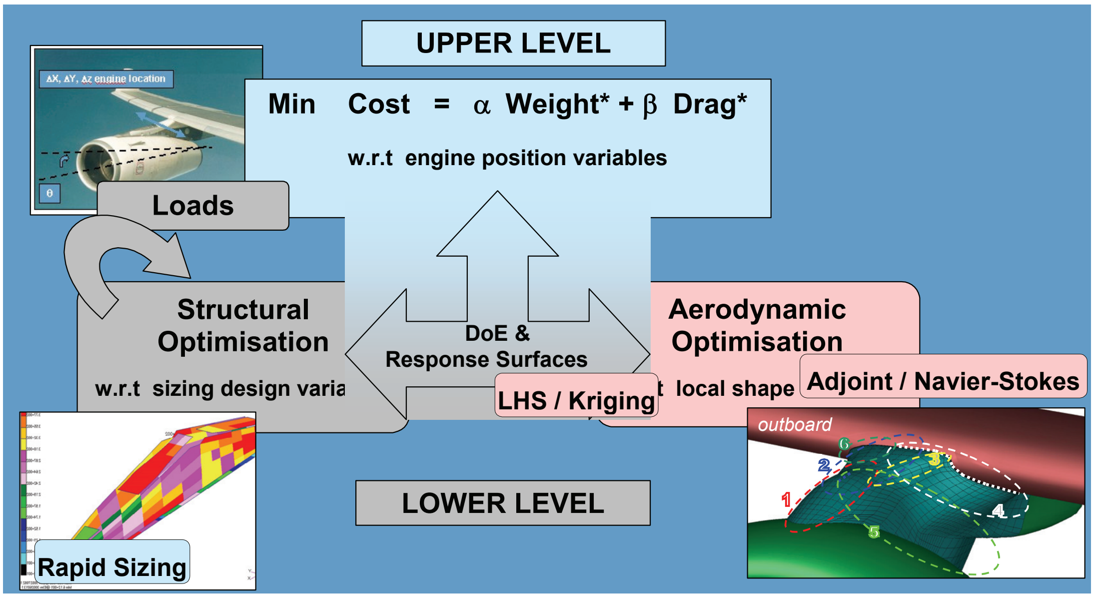


Figure 20: Stress and Aerodynamic Optimisation of Powerplant

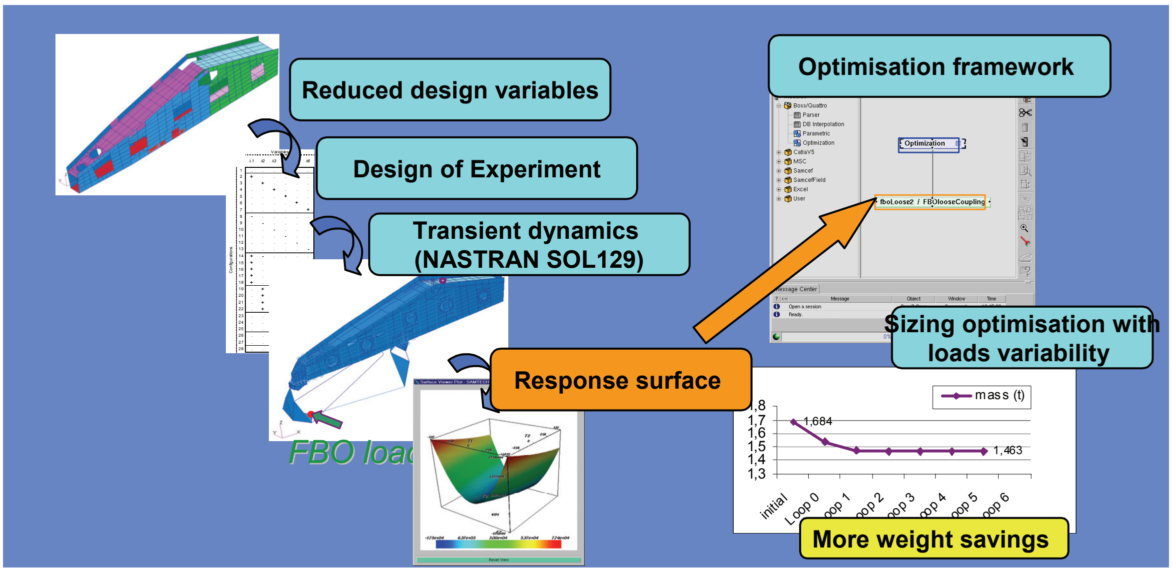


Figure 21: Stress and Loads Optimisation of Pylon based on Fan Blade-off Loads

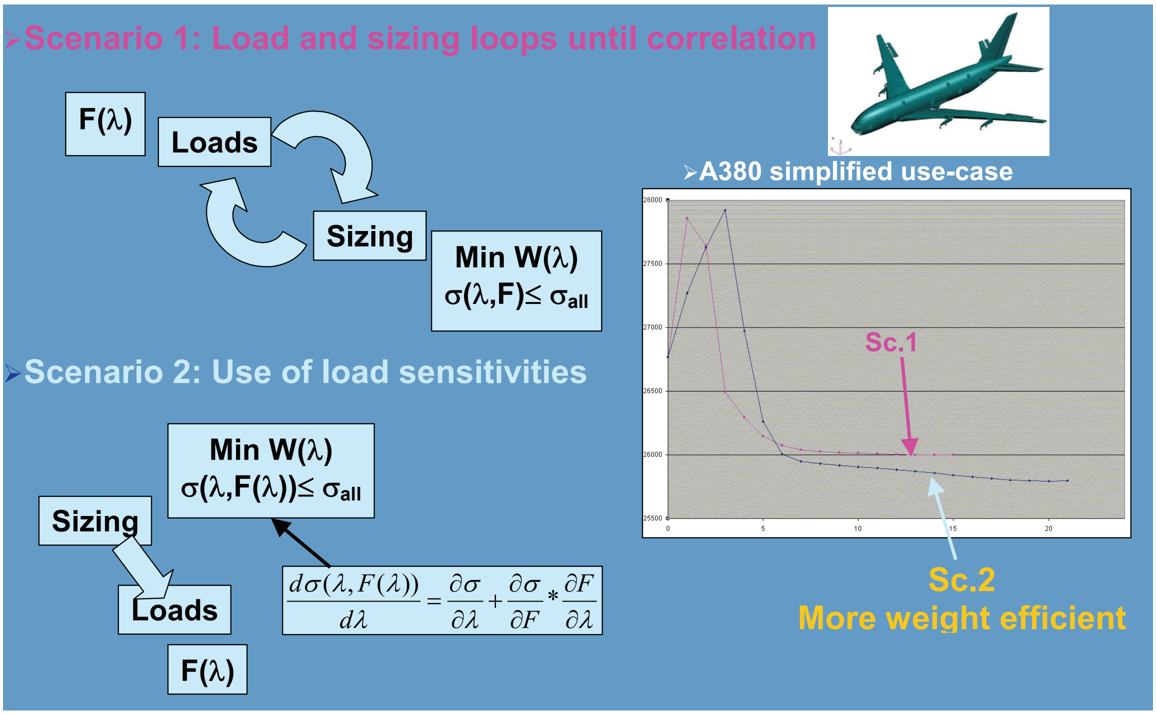


Figure 22: Stress and Loads Optimisation of Wing and Pylon based on Manoeuvre Loads

► Selected Publications

In addition to the presenting various aspects of the above achievements at the VIVACE Forum events, a selected list of related publications is provided below.

Rutka, A., Guenov, M., Lemmens, Y., Schmidt-Schäffer, T., Coleman, P. and Rivière, A., "Methods for Engineering Change Propagation Analysis", Proceedings of the 25th Congress of the International Council of the Aeronautical Sciences (ICAS), Stockholm, Sweden, 2006.

Lemmens, Y., Guenov, M., Rutka, A., Coleman, P. and Schmidt-Schäffer, T., "Methods to Analyse the Impact of Changes in Complex Engineering Systems", Proceedings of the 7th AIAA Aviation Technology, Integration and Operations Conference (ATIO), Belfast, Northern Ireland, 2007.

Sellini, F., Cloonan, J., Carver, E. and Williams, P., "Collaboration across the Extended Enterprise: Barrier or opportunity to develop your knowledge assets?", Proceedings of Tools and Methods of Competitive Engineering (TMCE) Symposium, Ljubljana, Slovenia, 2006.

Sellini, F., Cloonan, J., Carver, E. and Williams, P., "Working with the Supply Chain: Understand Barriers and Opportunities to Knowledge Sharing and Reuse", Proceedings of the 6th IDMME Conference, Grenoble, France, 2006.

Padulo, M., Campobasso, S., Guenov, M. and Maginot, J., "A derivative-free uncertainty propagation method for airfoil robust design", Presented at EUROMECH Colloquium 482 – Efficient Methods for Robust Design and Optimisation, London, UK, 2007.

Maginot, J., Guenov, M., Fantini, P. and Padulo, M., "A Method for Assisting the Study of Pareto Solutions in Multi-Objective Optimisation", Proceedings of the 7th AIAA Aviation

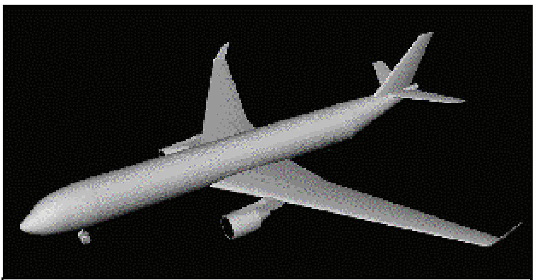
Technology, Integration and Operations Conference (ATIO), Belfast, Northern Ireland, 2007.

Bruyneel, M., Colson, B. and Remouchamps, A., “Discussion on some convergence problems in buckling optimisation”, Submitted to Journal of Structural and Multi-disciplinary Optimisation, 2006.

Colson, B., Bruyneel, M., Grihon, S., Jetteur, P., Morelle, P. and Remouchamps, A., “Composite Panel Optimisation with non-linear Finite Element Analysis and semi-analytical Sensitivities”, Presented at NAFEMS conference – Simulating Composite Materials and Structures, Bad Kissingen, Germany, 2007.

Grihon, S., “Industrial Implementation of Structural and Multi-disciplinary Optimisation at Airbus,” First International Conference on Multi-disciplinary Design Optimization and Applications (ASMDO), Besançon, France, 2007.

PREliminary and Unconventional Design (Prelude) for Global Aircraft



Single aircraft modelling integrating geometrical and numerical object design

Within the framework of VIVACE, the Prelude use case has developed an enhanced aircraft preliminary design environment based on an multi-disciplinary design optimisation (MDO) integration platform providing:

- An object driven integrated sizing and analysis tool
- A single aircraft model as a common resource coupling component and discipline modelling
- A merger of the two distinctive numerical and geometrical approaches

► Technical Objectives

The objectives for the Prelude platform are the following:

- A robust, flexible and dynamic workflow process
- A design process represented within a hierarchical organisation
- User access to the workflow at any level
- Visualisations of the workflow management and the calculation monitoring
- An object oriented modularisation
- User contributions described in a design-oriented language

While the objectives for the Prelude modelling are:

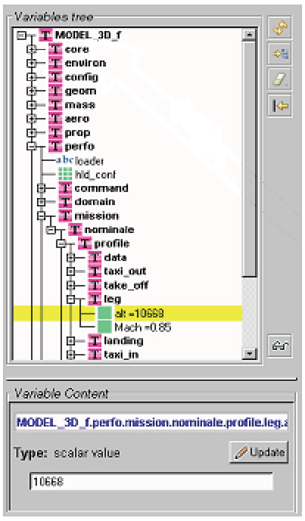
- Object oriented modelling
- A mix of the geometrical and numerical characteristics of the aircraft
- A component and discipline oriented architecture
- A shared consistent data structure for physical and operational aircraft design
- Dependency and sensitivity analysis treatments for technical risk assessment
- Uncertainty propagation with treatments for technical risk assessment

► Expected Benefits

- Availability of an integration platform as a test bed for research activities and Airbus internal studies.

- Innovative capabilities to study unconventional new configurations
- Coherent computation and homogeneous aircraft description in a multi-disciplinary environment with the promotion of a component and discipline object driven process
- Flexibility for the designer to build his or her own process as an element of the design data
- Easy sharing of studies due to the formalisation of data and process building
- Better understanding of complex processes and studies relying on hierarchical organisation and calculation monitoring
- Robustness of the results leading to a low risk assessment

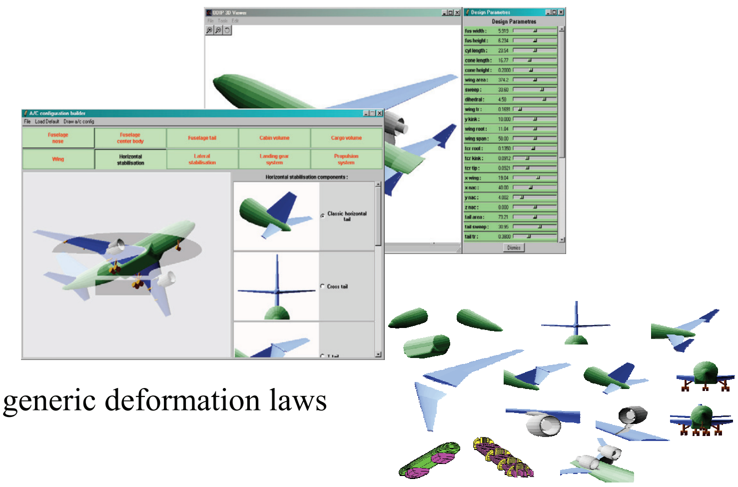
ACHIEVEMENTS



SINGLE MODELLING

One single MDO modelling driven by an object oriented approach to structure:

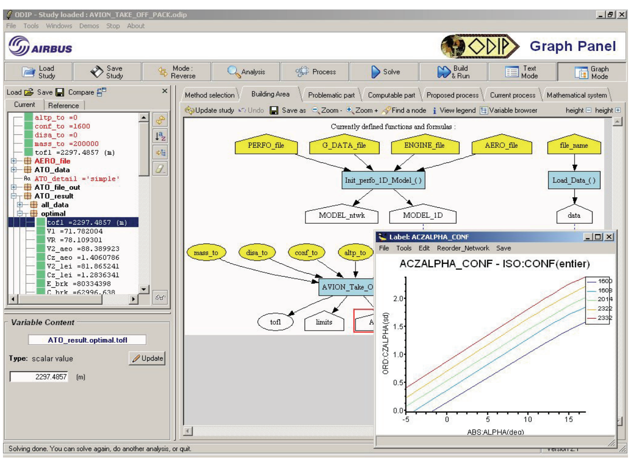
- A physical properties driven aircraft model (mass, geometry, aerodynamics, etc.).
- A component driven aircraft model (fuselage, landing gear, wing, etc.).



COUPLING NUMERICAL AND GEOMETRICAL DESIGN

Coupling numerical and geometrical design:

- Select components in a repository to assemble a configuration topology
- Modify the configuration according to generic deformation laws



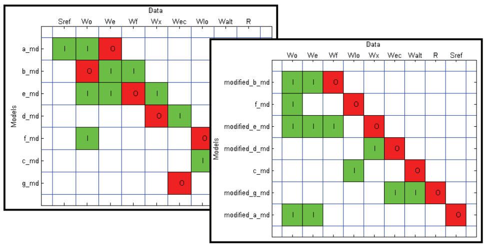
OPEN PLATFORM

Open and flexible experimental platform integrating numerical treatments:

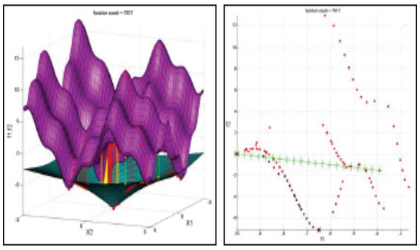
- Computational treatments (analyser, solver, and optimiser).
- Statistical treatments for result robustness.
- Visualisation treatments for result display.

Potential Candidate of the MDO Framework for Integration

The Workflow Manager is an analysis tool to facilitate calculation by improving the monitoring and the speed of computation.



Workflow Manager



Calculation Engine

The Calculation Engine is an optimiser providing high flexibility and effectiveness in the search for robust multi-objective design.

► Benefits Achieved

Test Bed

The Prelude platform is an innovative test bed for research activities and studies such as uncertainties management, performance and environment studies.

These activities allow validation of the platform against its use and its obtained results.

Innovation and Time Reduction

The use of an MDO object oriented model of the aircraft which allows the merging of numeric and geometric designs as an added value. This functionality allows:

- The designers to imagine new configurations.
- The reduction of conception time by the quick integration and assessment of these configurations.

Flexibility and Understanding

Hierarchical object oriented architecture ensures the flexibility:

- To build the workflow on demand.
- To store this workflow as part of the deliverable.

A format that is "run-able" and "editable" by the user for decision tracking purposes enables deep understanding and full control of a complex workflow.

Coherency and Sharing

Using a single MDO aircraft modelling ensures the consistency and high granularity of the description.

This capability has been used to exchange aircraft models with the team in order to perform a mutual validation through the Workflow Manager and a Calculation Engine assessment.

► WHAT'S NEXT

Within the PRELUDE use case, the maturity of the following activities can potentially lead to immediate research or industrial applications:

- MDO integration platform and single aircraft model
- Calculation Engine
- Workflow Manager

The Prelude integration platform will be used as a test platform for research activities.

Via collaboration with the existing university research team, industrial exploitation is expected of:

- The Calculation Engine in 2009 after an adaptation/piloting period in 2008.
- The Workflow Manager mid 2009.

Flight Physics Simulations Traceability

► TECHNICAL OBJECTIVES

This work focuses on the industrial integration of a data management and traceability solution in aircraft flight physics simulation, which is an important part of multi-disciplinary design processes and a key enabler for designing a virtual prototype. The question is:

How is it possible to efficiently interface various distributed multi-disciplinary computing environments with CAD systems such as CATIA V5 and with PLM/PDM software tools, to ensure numerical simulation / engineering simulation data management and traceability? This is a crucial capability in the context of a new aircraft design phase.

Engineering simulation data represent a small amount of data extracted from the whole set of numerical simulation data produced by a discipline and exchanged with other disciplines, or with partners.

Today, PLM/PDM and numerical simulation worlds do not interact efficiently:

- The traceability of numerical simulation parameterisation and results must be improved. It will have a significant impact on design process quality assurance and on repeatability of simulation tasks for rapid deployment of design derivatives;
- The control of the multi-disciplinary design workflow must be improved as well. Currently there is no synchronisation of concurrent processes, difficulties for design change acceptance, low maturity levels for engineering simulation data management and inter-discipline data exchanges
- The traceability of the access to product reference data (PDM, CAD, DMU) also has to be improved;
- Publication mechanisms for engineering simulation data and model configuration changes must be enhanced;
- A standard interface for the exchange of numerical simulation and engineering simulation data between different disciplines and different partners must be implemented.

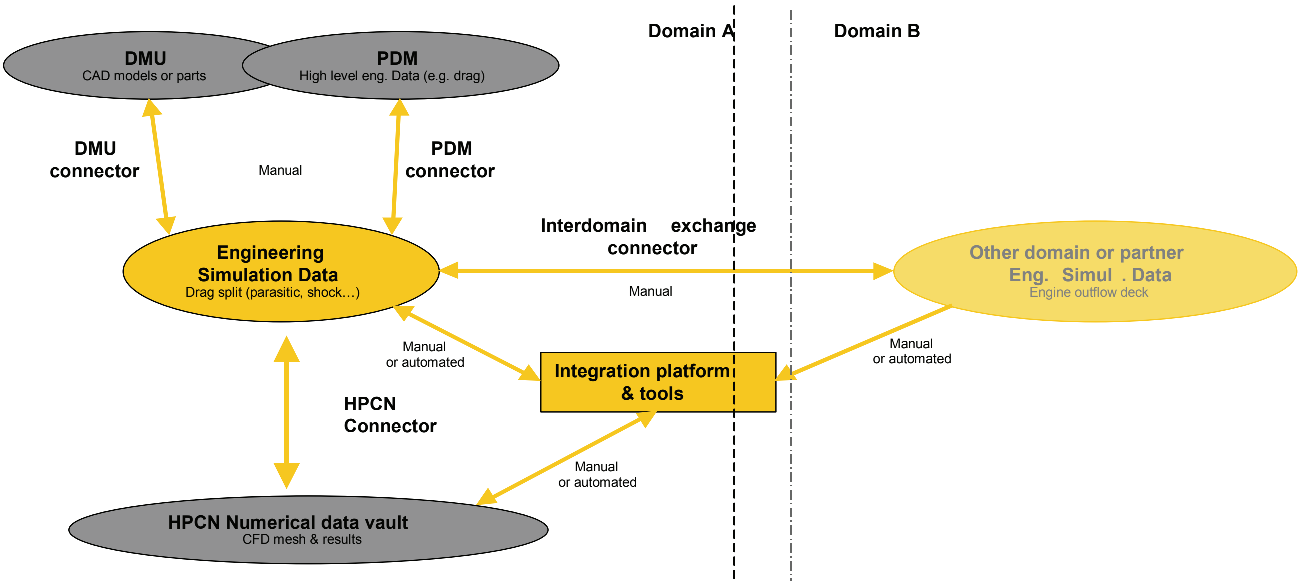
Therefore, the objective of the work is to address the following topics:

- Making the simulation world visible to PLM/PDM and vice versa;
- Enabling enterprise-wise sharing of numerical simulation and engineering simulation data;
- Ensuring the traceability and repeatability of numerical simulation data and multi-disciplinary processes.

The major preliminary needs, jointly identified and agreed by the industrial partners within this work package, are:

- A scientific view of PLM/PDM;
- The creation/implementation of inter-discipline connectors;
- The creation/implementation of an engineering simulation data layer;

- The creation/implementation of bilateral connectors between PLM/PDM and the engineering simulation data layer;
- The creation/implementation of bilateral connectors between engineering simulation data layer and the whole set of numerical simulation data produced by every discipline;
- The creation/implementation of multi-enterprise communication standards and tools, which is a mandatory step towards the virtual enterprise.



The ultimate objective of the final industrial use cases is to validate the quality enhancement of the partners' multi-disciplinary design processes using a common data management and traceability software solution, operated in various design and computing environments.

For every identified technical and functional requirement, the consortium has analysed the existence of any technical solution and if existing, its compliance with the partners' requirements. Then a development or adaptation phase of the software tools has been conducted (within the EDM work package) in an incremental way to efficiently control any technical risks. In the same way, tests and validation have been performed regularly by the final end-users to give important feedback to developers. Industrial demonstrations have been conducted for the final validation of the software tools and the evaluation of the benefits of using it.

► Current Achievements

The following activities have been carried out:

- Collecting the technical and functional user requirements;
- Defining the industrial use cases used for carrying out the validation of the different releases of the Traceability Software solution;
- Defining the validation roadmap;

- Performing the technical evaluation of the traceability software solution. This evaluation has been carried out by running partners' use cases with the PLM solution ENOVIA LCA V5R16 (also called PLM solution) from Dassault Systèmes. As, jointly agreed by the workpackage industrial partners, the major outcomes of the evaluation steps are:
  - The PLM solution concepts for Flight physics simulations traceability are practicable;
  - The potential of the evaluated PLM solution is extremely high, but in a industrial context, some simple but more immediate features are required;
  - Some traceability capabilities implementations have to be slightly re-visited (reduction of manual tasks) to fully match industrial users' needs.

Thanks to the VIVACE Project:

- Users' needs in term of Flight physics simulations traceability have been fully captured;
- Ways to adapt/enhance multi-disciplinary numerical processes have been clearly identified;
- Traceability methodologies set-up during the Project will be implemented in future operational programmes.

Complex Subsystems Design

The design of complex sub-systems, such as a helicopter rotor, needs to take into account a variety of completely different issues, such as performance, specifications, configuration, geometry definition and validation by calculation. To reduce the time-to-market, these issues must be tackled simultaneously by many people in several companies.

Our first objective was to make the design of very complex mechanical sub-systems more efficient by improving and integrating the different tasks that constitute the design process:

The first challenge was how to build a design toolbox that answers the Design to Market concept:

- **To be used throughout the design phase to ensure product optimisation of a mechanical sub-system;**
- **To ensure simulation and engineering data management and traceability.**

Our second objective was to define ways and means for the aeronautical industry to make the pre-design process efficient for the definition of a complex design upgrade or a new development:

The second challenge was how to use all available knowledge at the very beginning of a new project to develop solutions fulfilling technical and financial customer requirements. The design of a very complex system makes the use and management of past experience a crucial capability that is mandatory in the context of an upgrade/new design.

These two questions have been answered by the following services:

► INTEGRATED DESIGN

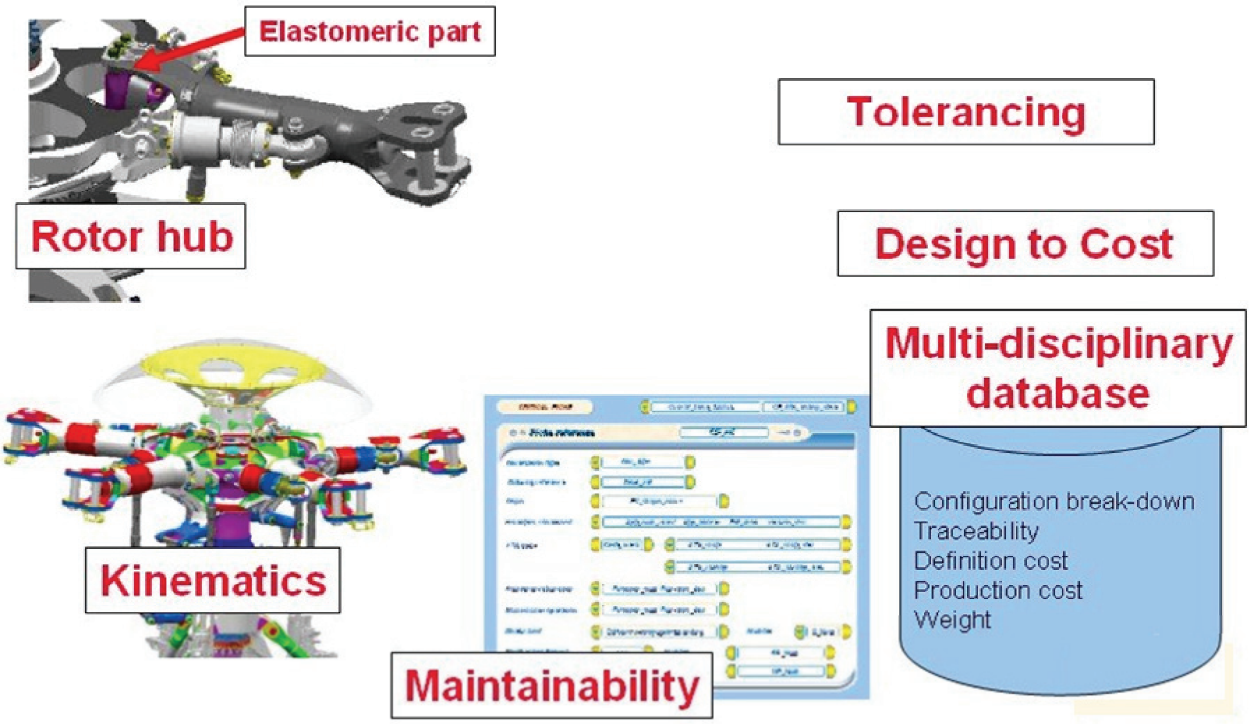


Figure 23: Integrated design

Integrated Design is dedicated to complex system design improvement through the definition and deployment of specific methodologies, the development of effective specific tools and their integration within a common environment.

The underlying use case is a helicopter rotor design. During the whole design process, several topics are involved, and among them the following have been handled in the VIVACE project:

- Upper hub pre-sizing including elastomeric parts such as spherical bearings;
- Kinematics to define new methods which take into consideration the new CAD functionalities;
- Tolerancing to improve the relevant methods for complex designs;
- Maintainability to supply the designer with the corresponding constraints;
- Design to market aspects to provide the designer with the input and constraints necessary to take into account the customers needs;
- Multi-disciplinary database to allow the designer to access all the necessary data.

Main achievements

Solutions for "Rotor Hub Pre-dimensioning", "Kinematics", "Maintainability", "Design to Cost" and "Multi-Disciplinary Data Base" have been developed and corresponding user's guides are available.

The "Tolerancing" methodology has been defined and the methodology guide is available.

▶ PRE-DESIGN PROCESS IMPROVEMENT

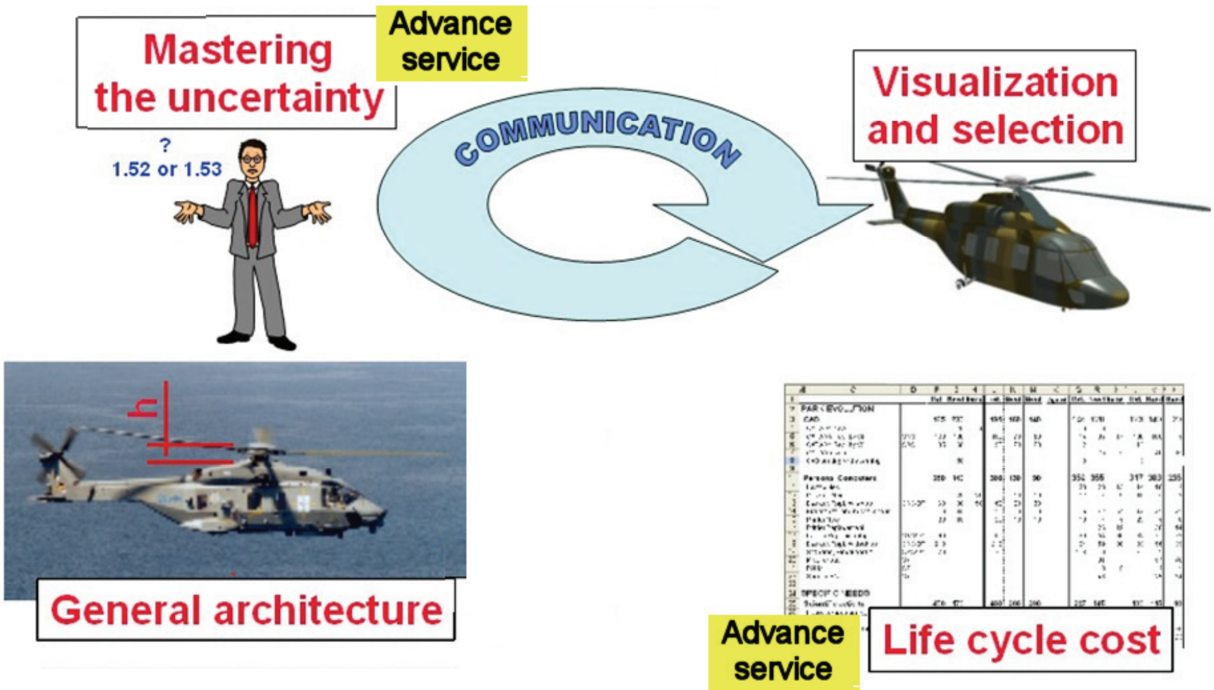


Figure 24: Pre-design process improvement

Within the aeronautical industry, helicopters have particularities such as:

- Multiple customers and missions;
- Market characteristics: small series and low self-financing capacities;
- Difficulties for a global simulation of a complex mechanical system;
- A high level of product integration.

These constraints have a significant impact on the helicopter pre-design phase.

Within the framework of VIVACE, we have improved the process by developing new methods and tools for the following topics, allowing better communication and experience feedback re-use:

- Mastering the uncertainty: risk analysis;
- General architecture: formalising the process to make it easier and quicker;
- Life Cycle Cost: optimisation of cost for multiple customers and missions;
- Pre-design digital mock-up: visualisation of large assemblies with quick changes according to multi-missions capabilities.

Main achievements

The solutions for these four topics have been defined using:

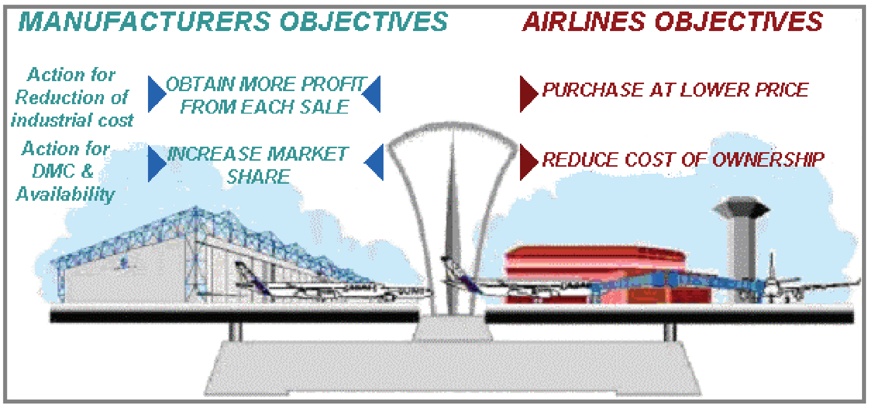
- Specific development for “Mastering the Uncertainty” and “Life Cycle Cost”

- Methodology definition for “General Architecture” and “Pre-design digital mock-up visualisation”.

The user’s guides and methodology guides have been delivered.

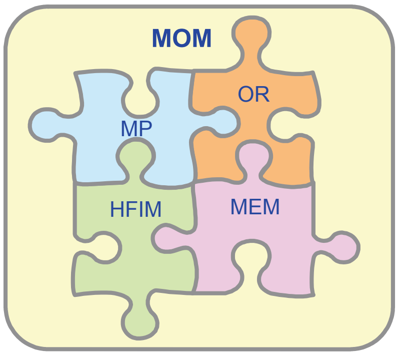
Supportability Engineering Activities

In a more and more aggressive economic environment for airlines, the Aircraft manufacturer has to provide a competitive product, both in terms of initial price and operating performance



In this context, the supportability engineering disciplines have to be introduced for the concurrent design of a product and its support in order to meet customers' operational needs, implying good reliability, maintainability and low operating costs. Supportability engineering participates therefore integrally in the design of a product to deliver the minimum operating cost to the operator while ensuring optimal availability and operational reliability.

Today, each supportability discipline manipulates its own models and data with few interactions between them and with industrial partners. Thus, within the frame of VIVACE, the supportability engineering overall objectives are to share methods and way of working between aircraft integrator and suppliers but also to create a European standard for supportability engineering activities.



To reach these objectives, the VIVACE supportability engineering activities has focused on the following disciplines, each one corresponding to a dedicated task:

- Maintenance Optimisation Model – MOM

The objective was to develop an efficient means to perform different trade-offs regarding an overall supportability performance. The main drivers will be based on design alternatives, architectures and on maintenance concept.

- Maintenance Economic Model – MEM

The objective was to develop and establish methodologies & models to carry out qualitative/quantitative assessments for structure Direct Maintenance Cost (DMC) & system troubleshooting DMC

- Maintenance Programme – MP

The goal was to improve the scheduled maintenance on current and future aircraft models by improving the determination and evolution of maintenance task intervals.

- Operational Reliability – OR

The goal was to set up a model integrating all relevant and predictable influencing parameters to forecast the in-service behaviour of a given design regarding operational interruptions (delays/cancellations, etc.), but also aircraft availability.

- Human Factors in Maintenance – HFIM

The objective was to develop a methodology assessing the contribution of maintenance human factors performance in the previous supportability models.

Main achievements

All the models have been developed and validated.

The Virtual Engine – An Overview

The VIVACE high-level objective relevant to the Virtual Engine sub-project is to contribute to the 30% reduction in lead-time and 50% reduction in development costs for a new engine. In this context the term "contribute to…" simply acknowledges that not all areas have been able to be addressed within VIVACE. For those that have, lead-time and cost reductions are anticipated to the level stated. In order to achieve this five areas of interest have been addressed.

1. Extended Jet Engine Enterprise Scenario
   - At a high level, developing a greater understanding of the virtual engine business environment has been seen to be important. Models and tools have been produced to aid the assessment of that environment and to evaluate the impact that potential events could have on the model.
   - Building on the work done to model the business environment, the next step was to move to a more detailed phase of modelling, aimed at understanding the behaviour of the aero engine value chain
   - Recognising the need for collaboration between companies has led to the development of methods to accelerate the ability to produce customer proposals in a collaborative environment.

2. Life-Cycle Cost Modelling
   - It is usual in today's business environment that European Aircraft Engine Industries form collaborations. To work in collaborations with three, four or more companies consumes time and money especially when seeking common agreements on Life Cycle Cost Nomenclature, Structure, Input and Output Parameters. Today, this process lasts twelve or more months, due to different Standards and different Life Cycle Cost Models. As a result of the work in VIVACE this time can be greatly reduced.

3. Whole Engine Development
   - The Whole Engine Development work package is the practical realisation of the Virtual Engine concept. In this vision the model is created from the first definition of the geometry and includes all of the boundary conditions, constraints and thermo-mechanical duty that completes its definition; whole engine air system and thermal models are incorporated. This theoretical model then becomes the physical understanding of the behaviour of the engine. The work has addressed five related themes:
     - Whole engine preliminary model direct from the 3D digital design;
     - Strong links between analysis and physical measurement;
     - Automated whole engine model updating through the design cycle;
     - Broader application of robust design practice;
     - Robust processes for parametric component design.

4. European Cycle Program: a shared gas turbine performance tool
   - The main objective of this work package is to develop a vehicle that facilitates the optimal use of R&D resources and smooth co-operation, especially in European co-operative programmes. A comprehensive, multi-disciplinary, object-oriented simulation environment has been proposed to integrate all European gas turbine simulation technologies into a single framework providing shared standards and methodologies for European universities, research institutes and companies. This simulation tool is named PROOSIS: **PR**opulsion **O**bject **O**riented **SI**mulation **S**oftware. "Proosis" is an ancient Greek word meaning "propulsion".

5. Supply Chain Manufacturing Workflow Simulation
   - In order to achieve the aim of reduced development lead-time and costs, activities outside of that period, but which have a significant potential impact on the design and development activity also need to be addressed. For that reason Supply Chain modelling work has been undertaken which, as well as modelling for new manufacture, can also address service supply chain issues.
   - Historically, hardware has been designed without much regard of its effect on the overall production process, including the supply chain and the subsequent effects on future business concepts. However, the production community has started to acknowledge the importance of the design of the supply chain in the hardware design process. Especially so as the attributes of the supply chain have a significant impact on the possibilities to successfully establish new competitive business concepts that will reduce the cost of travel. The main objective of the work package is therefore to develop new concepts to develop products considering logistical aspects and to design and model the manufacturing workflow in the company and the supply chain.

The main strategy of the virtual engine activity is to enable more analyses to be performed earlier in the design process. In the early design stage there is a much greater opportunity to optimise designs and, as the design is progressed, the objective is, where possible, to reduce costly testing through the creation of high fidelity models. The focus, therefore, is on improved modelling capability, improved data transfer methods and key to it all – is a focus on validation of new methods.

The chapters following provide much more detail of the achievements in each of these fields. A key strategy behind the success of VIVACE has been to develop Use Cases. These are realistic examples or simulations relevant to the technology being addressed. They have been used to focus the research and to assess the success. In each of the five areas use cases have formed the backbone of the work.

Extended Jet Engine Enterprise Scenario

This work explores the future requirements for the aero engine industry in terms of both products and services. Models investigate the possible effects of alternative business environments, business models, value chain configurations and engine service strategies. Ways in which a virtual enterprise will need to co-operate and share information have also been proposed, in order to produce fast and efficient customer offers.

Participants in the work are Volvo Aero Sweden, Rolls-Royce plc UK, UNOTT UK, UNIMAN UK and LTU Sweden.

► BUSINESS ENVIRONMENT MODELLING

Possible future business environments

A novel software prototype, 'VIBES' (VIVACE Interactive Business Environment Simulator) was created, demonstrating how a future business environment could be formed from a range of standard scenario elements. There are nineteen 'dimensions' within which a future environment can be plotted, addressing issues such as conflict, the power of the environmental lobby and the proportion of 'no frills' airline offerings.

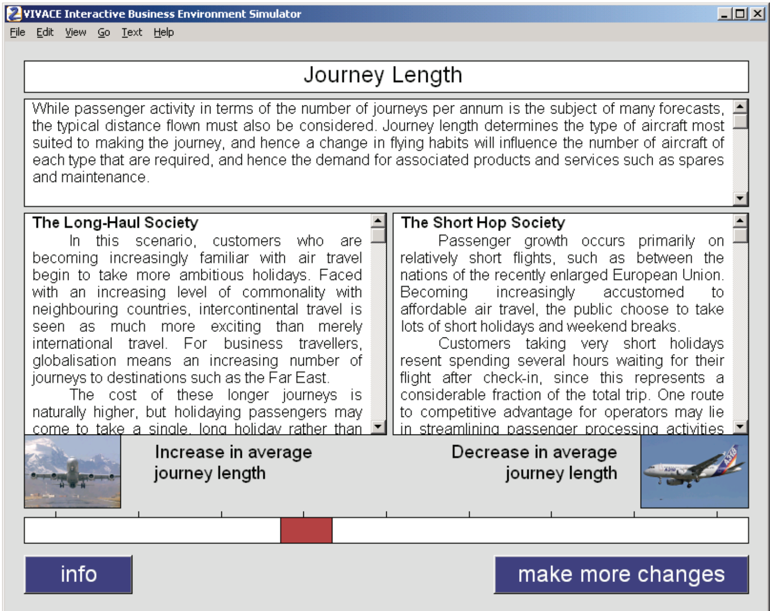


Figure 25: Screen display from VIBES – a prototype tool to support scenario planning in an aerospace context

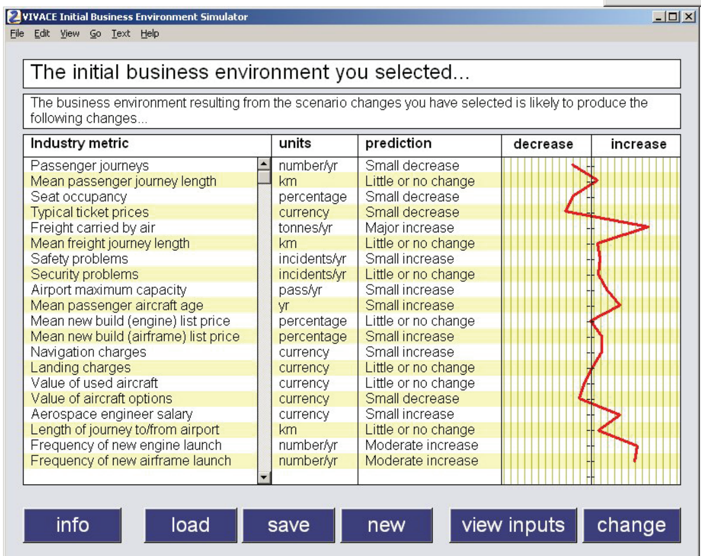


Figure 26: Rough-cut forecast produced by VIBES, showing a future business environment in order to stimulate strategic thinking

These investigations led to several key themes being identified; these were business environment concepts that featured in many of the models created by industry stakeholders. These themes were then used as inputs in the value chain analysis and business model evaluation activities.

► VALUE CHAIN MODELLING

Building upon the work done to model the business environment, the next step was to move on to a more detailed phase of modelling, aimed at understanding the behaviour of the aero engine value chain. System dynamics tools were used for a detailed study of the behaviour of key aspects of the market for aerospace products and services, including the behaviour of key industry players.

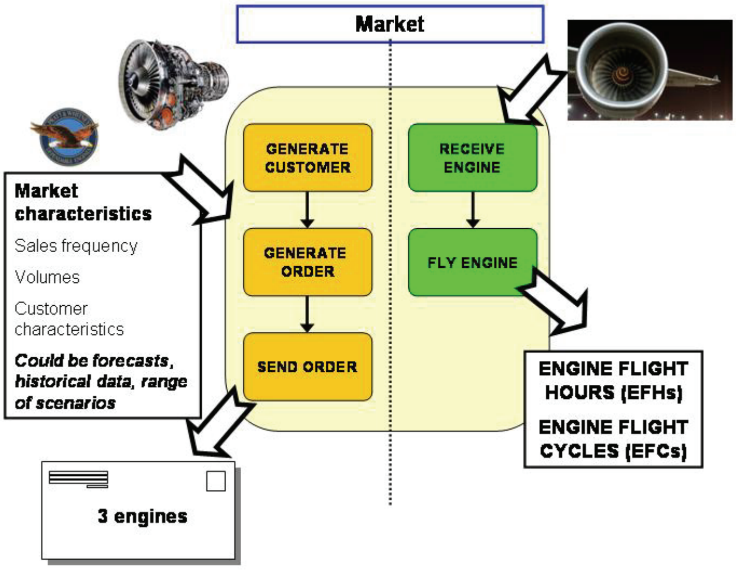


Figure 27: Architecture of the system dynamics model, showing influences upon the demand for aircraft

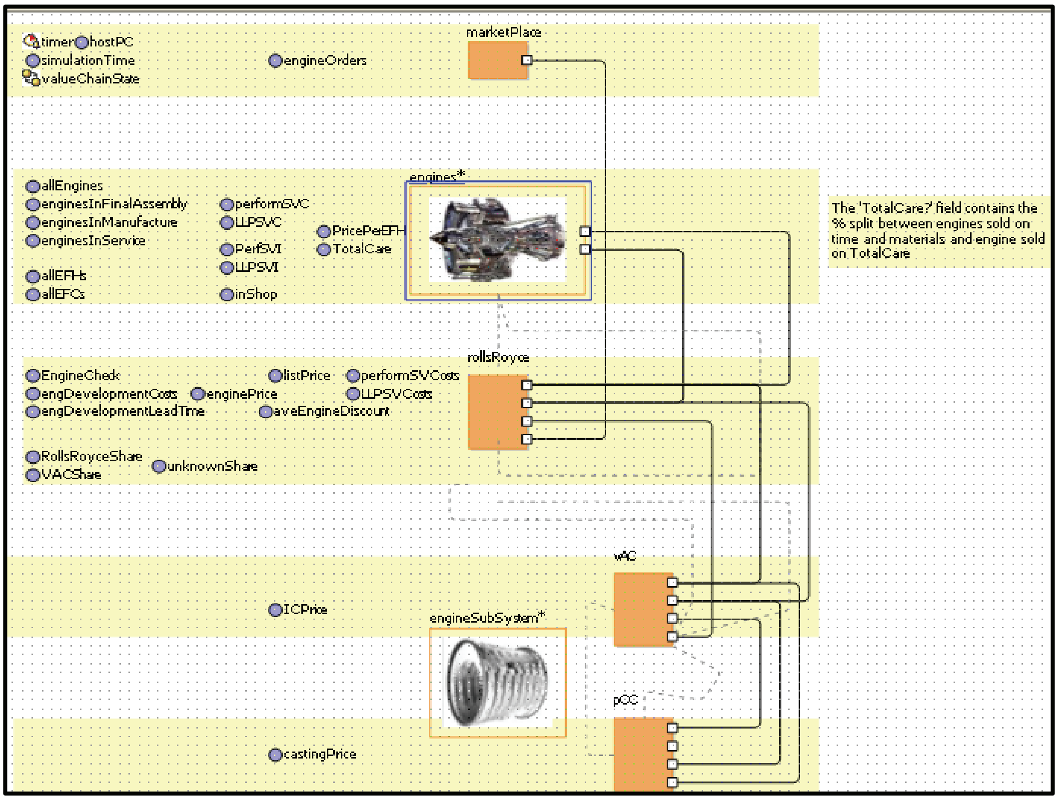


Figure 28: Screenshot from the system dynamics model, implemented within AnyLogic

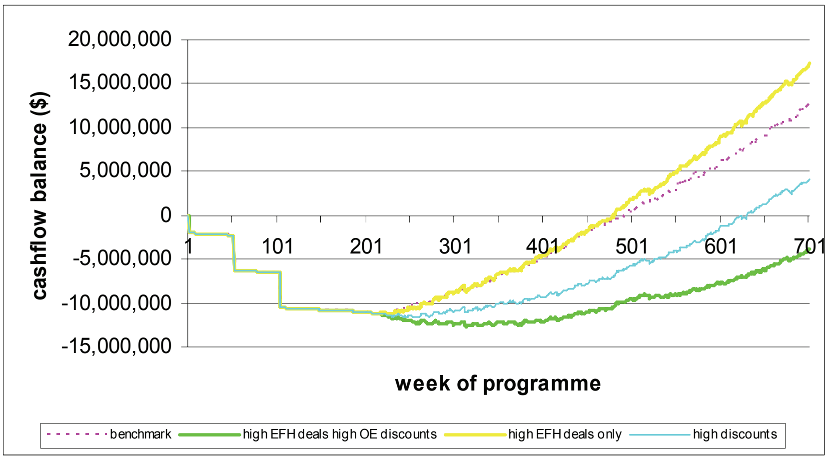


Figure 29: Sample result from the system dynamics modelling work, showing whole lifecycle cash flows under four different scenarios

► THE AERO ENGINE BUSINESS MODEL

The development of a possible future business models for the aero engine industry requires both creativity and structure. Existing approaches were examined and a mapping approach was selected, for use during several investigations. These studied the present-day aero engine business model, and potential alternatives for the future; further investigations studied business models from other industries. This led to the identification of a number of generic "business model components" that had been seen to work elsewhere (for example, in entertainment, healthcare, communications and retail). Creative methods were applied to the development of possible future aero engine business models, examining the models for primes and their partners. The generic process was formalised as the 'Business Model Mapping Methodology', which challenges assumptions and encourages the consideration of alternatives. Links with the value chain modelling tools allowed quantitative analysis of the business models that were derived.

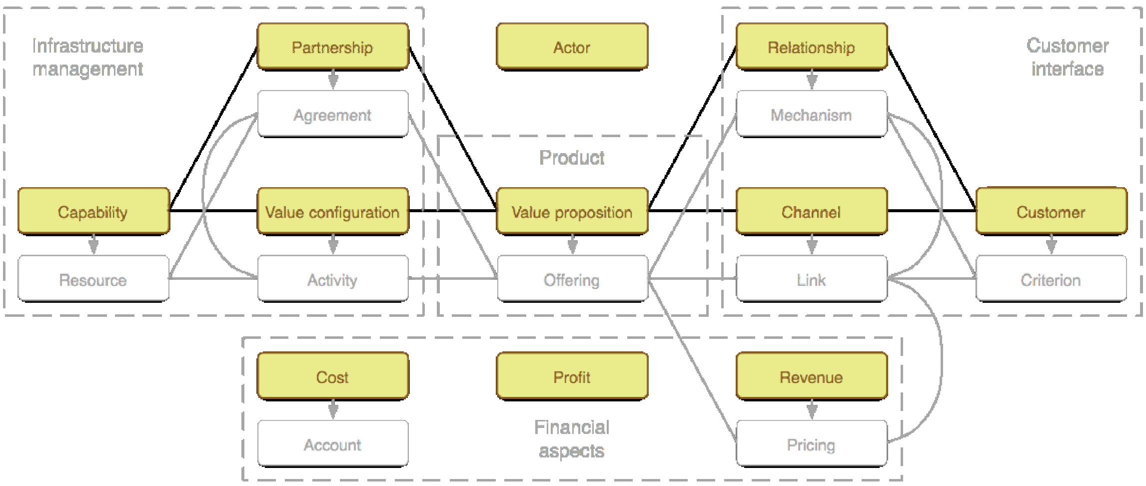


Figure 30: The adopted business model ontology [Osterwalder, 2004]

► SERVICE DESIGN AND SIMULATION

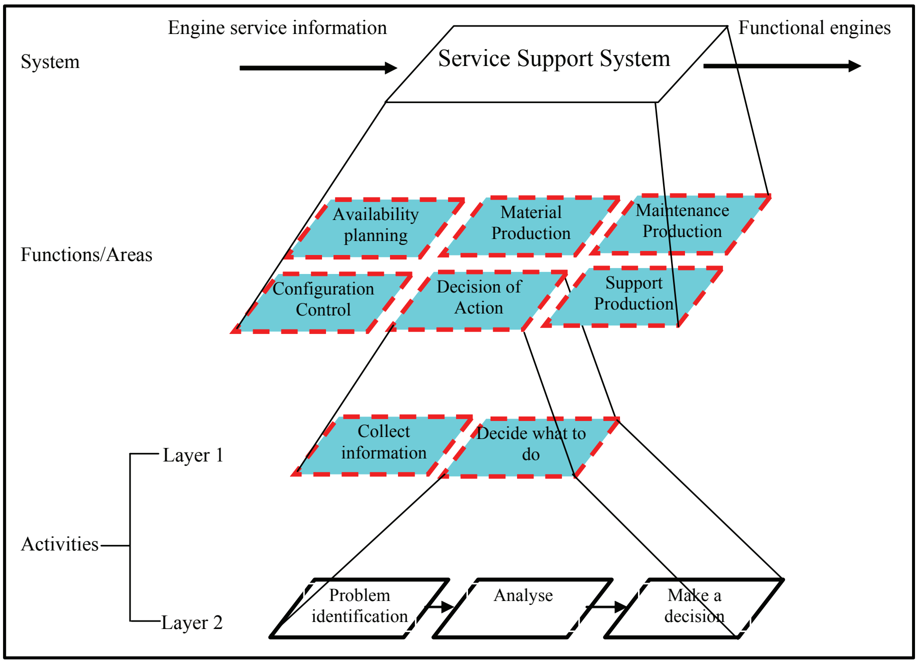
Three areas have been addressed in order to apply modelling tools to a service application:-

(1) A description of the service support system for aircraft engines, including an overview of the service system, service types and service processes

(2) A description of the simulation model, including an overview of the model, inputs and outputs, methodologies and factors that have been taken into account, and the functions of the model

(3) Operating instructions for the simulation computer model, including the system requirements, steps to generate inputs, running the model and viewing the simulation results

Figure 31: Overview of the Service Support System



► THE SEVEN-DAY PROPOSAL

When several independent companies want to produce a proposal jointly, for a potential customer, pre-defined working routines are necessary in order to maintain pace and assure quality. The *seven-day proposal process* outlines a workflow for collaborative proposal generation. It is a concurrent process, i.e. with several sub-processes running simultaneously, divided by gates into seven phases. The gating of the process means that the work from a previous phase has to be scrutinised and approved before the work can continue in the next phase, ensuring quality and accuracy.

In order to give accurate support to the activities in the process, a support system is an essential complement to the process. The seven-day proposal system identifies the kind of tools, models, guidelines and information that are needed to produce proposal and decision-support documents of high quality. Trust among the involved partners is also emphasised as an important factor that must be present within the virtual enterprise to ensure a fruitful collaboration.

For this process to work, a number of preparations are crucial, including the business model to be operated, the means by which information will be shared and the role of information and communication technology. These basic rules for collaborative work have been identified as prerequisites for the demonstration of a seven-day proposal process in practice.

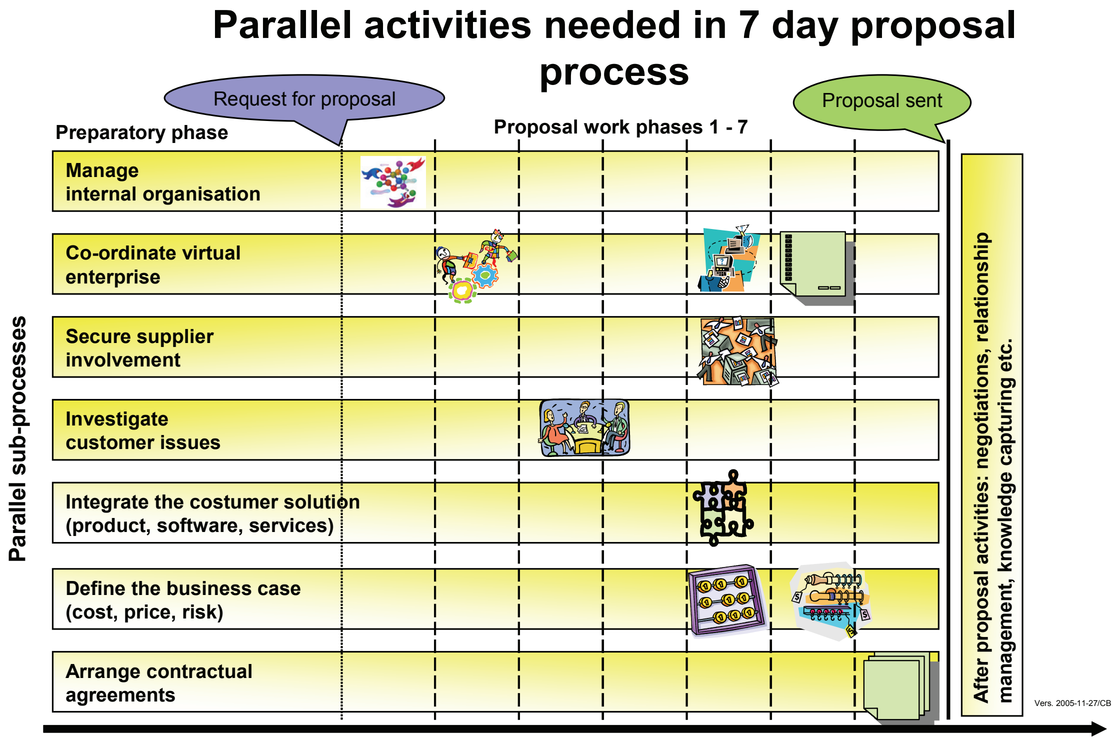


Figure 32: Overview of the 7 Days proposal process.

Managing the collaborative proposal process

In today's highly competitive industry, project management plays a vital role in the success of a company. It is a new way of thinking about emerging problems and identifying solutions. This approach has been applied to the seven-day proposal process and the outcome is an appropriate project management methodology. The work has involved an extensive review of project management principles and associated tools. Suitable principles and tools to manage each group of activities for each phase of the seven-day proposal process have been identified.

It is emphasised that the seven-day proposal process cannot be managed by the application of a single project management tool. However, combining a suite of project management tools and applying them in a particular configuration, identified within this research, can yield effective management of the seven-day proposal process. The proposed methodology is generic and can be applied to at any level within the supply chain.

► ACHIEVEMENTS

Seven technical results are offered as outcomes from the Extended Jet Engine Enterprise Scenario work. These are tools and methods that can be used to facilitate the set-up of a virtual enterprise, to explore and evaluate new business models, and to assist during the process of generating a proposal to a potential customer. All results have been validated through consultation with industry experts, and document review.

Result	Short description
Factors map	A tiered, graphical map showing the issues that act upon and within the industry, affecting the market for air transport and its enabling services.
VIBES	A demonstrator that allows planners to conduct scenario-based analysis, rapidly constructing, capturing and sharing descriptions of future aerospace business environments.
Process and system description for seven-day proposals	Outlines of a collaborative workflow, i.e. activities to be performed in order to produce a proposal to a potential customer. Identification of needed information/tools (services) to be used during the work.
Service simulation model	Applicable when "total care" services for products are provided. Allows us to rapidly construct a model of a service support system and analyse its performance with simulation.
Business model mapping methodology	A structured method for analysis of business models, allowing potential problems or opportunities to be identified.
Value chain modelling tool	Uses an agent-based modelling principle to simulate the operational and financial performance of the complicated network of virtual enterprise companies, over the duration of an engine programme or for a market sector (i.e. single aisle aircraft).
Project management methodology for the 'seven-day proposal process'	Project management principles and tools suitable to manage each group of activities for each phase of the seven-day proposal process have been identified and tabulated.

Additionally, support has been given to Knowledge Enabled Engineering, resulting in the Gated Maturity Assessment tool. This can be used to assess the maturity of information/knowledge in a decision process, such as the seven-day proposal process. Also the VEC-Hub concept work, performed within Collaboration Hub for Heterogeneous Enterprises, has been supported. A validation of the appropriateness of the VEC-Hub concept for a seven-day proposal process has been performed.

Benefits

The expected benefits to be achieved by applying the results of this work can be summarised as follows.

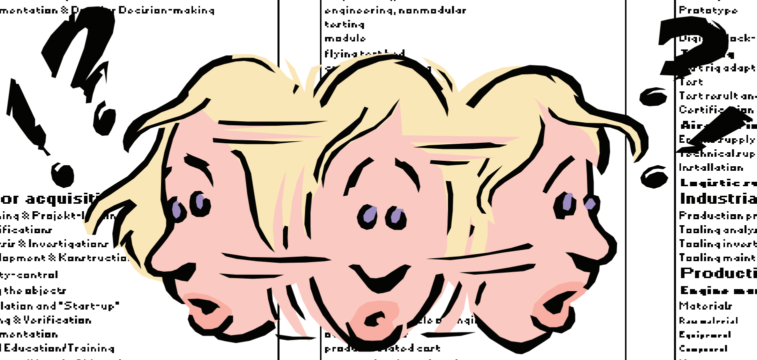
- The technical results focus on the decision process and provide means to support the human process of making decisions. The decision process can thus be facilitated and *better decisions can be taken faster.*
- Also *risk can be reduced* as the tools give us additional *knowledge* earlier in the decision-making processes and provide us with opportunities to simulate/work with different scenarios.

- When several independent partner companies make use of the shared working process and support tools for producing proposals additional benefits will be provided;
    - An agreed and shared working procedure will *facilitate the practical collaboration.*
    - *Confidence for decision-makers* can be achieved by assured quality of proposal and decision-making documents.
    - Compared to not using a shared workflow and support tools, this practise will imply *reduced man-hour time* and *cost* for proposal generation.
    - Improved trust through *better understanding* of the actions of partners, brought about through the use of a common ontology (world view).

Life Cycle Cost modelling

In today's aero engine business it is very expensive to bring a new product into the market. Therefore it is usual that European Engine Industries form collaborations. To work in collaboration with three, four or more companies consumes time and money especially when reaching common agreements on Life Cycle Cost Nomenclature, Structure, Input and Output Parameters. Today, this process lasts twelve or more months, due to different Standards and different Life Cycle Cost Models.

	Company A	Company B	Company C
LCC- **A**quisition	**Cost for research and development** - for Planning & Projekt-leading - for Specifications - for Analysis & Investigations - for Development & Prototyping - for Testing - for Evaluation & Control - for Software Development - for Documentation & D[illegible] Decision-making **Cost for acquisiti**[illegible] - for Planning & Projekt-l[illegible] - for Specifications - for Analysis & Investigations - for Development & Konstructio[illegible] - for Quality-control - for Bying the objects - for Installation and "Start-up" - for Testing & Verification - for Documentation - for Initial Education/Training - for Software (if not in Objects) - for Workshops & Promesis	**Development data elements** part certification effort detailed design work breakdownstructure engineering manufacturing hardware engineering, modular engineering, nonmodular testing module flying test bed [illegible] production related cost non-production related cost general arrangement dimensions special features spare engine spare module spare accessories initional provisioningspare parts maintenance tooling contracts finance monitoring bill of material packaging handling	**Pre-developement cost** Market analysis Pre-design analysis / feasibility **Development costs** **Design** Design requirement breakdown / Specifications Preliminary design Detailed design **Prototyping** Designset Tooling definition & manufacturing Prototype Digi[illegible] Mock-up **T[illegible]g** [illegible]t rig adaptation Test Test result analysis Certific[illegible]ion documents **Air[illegible] installation** E[illegible] supply [illegible]chnical support Installation **Logistic support** **Industrialization** Production process definition Tooling analysis (line/shop) Tooling investment/manufacturing Tooling maintenance **Production** **Engine manufacturing** Materials Raw material Equipment Component Human resources [illegible] **Spare manufacting** **Delivery** **Logistic support** Initial training Manuals **Others Acquisition costs** **Initial Provisioning (line/shop)** **Interest/depreciation** **Insurance**
Life **S**upport **C**ost	**Cost Initial for resource for maintenance** - for Maintenance engineering - for Spareparts (LRU, SRU, DU, DPp, DPs) ...at Operational-Level ...at Intermediat-level ...at Depot-level	**Operating & Support Data Elements** fuel, oil & lubrication basic engineeringsupport maintenance labour data maintenance material data programme management	**Operating cost** **Fuel burn** Deterioration / restoration **Maintenance (materials, man hours)** Line/shop LLP



We have gathered and integrated a broad range of knowledge and competencies from European aeronautic companies. A common European Standard for Life Cycle Cost Modelling regarding Nomenclature and Structure has been agreed and established. The data formats generated are standardised and stored in a tool library for future traceability.

About 150 major Cost Elements and Cost Relationships, out of more than 300 different Cost elements used by the participating companies, have been identified and agreed. These elements have been structured into a 4-Level Life Cycle Cost Breakdown Structure.

LCC nomenclature			
Level 1	**Level 2**	**Level 3**	**Level 4**
Development Cost	Pre-development cost	Engineering	Design Programme management
		Hardware	Components for test rig construction Components, modules and engines for testing Tools
		Testing	Test rig adaptation Test object assembly/disassembly Instrumentation Test Test results analyses Test of new material
	Detailed development cost	Engineering	Design drawings Design studies Design instrumentation Programme management Supplier selection R/M/S Analyses Certification
		Hardware	Components for test rig construction Components, modules and engines for testing Tools
		Testing	Test rig adaptation Test object assembly/disassembly Instrumentation Test Test results analyses Test of new material
	Post-development cost	Engineering	Modification analyses Re-design Programme management Supplier selection R/M/S analyses update Certification update
		Hardware	Components for test rig construction Components, modules and engines for testing Tools
		Testing	Test rig adaptation Test object assembly/disassembly Instrumentation Test Test results analyses Test of new material
Industrialisation Cost		Engineering	Production process Programme management Supply Chain build-up Machine programming
		Production tools	Tooling Investment

Figure 33: 4 Level Cost Element Structure (partial).

The standards produced by this Work Package have been built directly from the knowledge of each participating organisation. As a consequence, the dissemination of this work will depend on the confidentiality level applied by all the contributing Work Package partners.

So, it will result in particular choices for the diffusion of each deliverable. Therefore, training will be provided as a function of this diffusion level. Restricted deliverables will only be taken into account for training internally organised by firms represented in the Work Package. Consequently, on the one hand, the work done during VIVACE project will be the basis of improvement in Work Package participants' knowledge about Life Cycle Cost simulation methods; on the other hand, full public diffusion enables every organisation that has access to relevant VIVACE documents, to use this knowledge and to provide external training.

After having agreed and established the Standard and Nomenclature, the Life Cycle Cost Math Model was built up. The basis for the mathematical algorithms is all the cost influencing parameters. About 50 parameters have been analysed and built up in a cost Dependency Matrix. Out of that work the Cost Estimation Relationships (CERs) have been created.

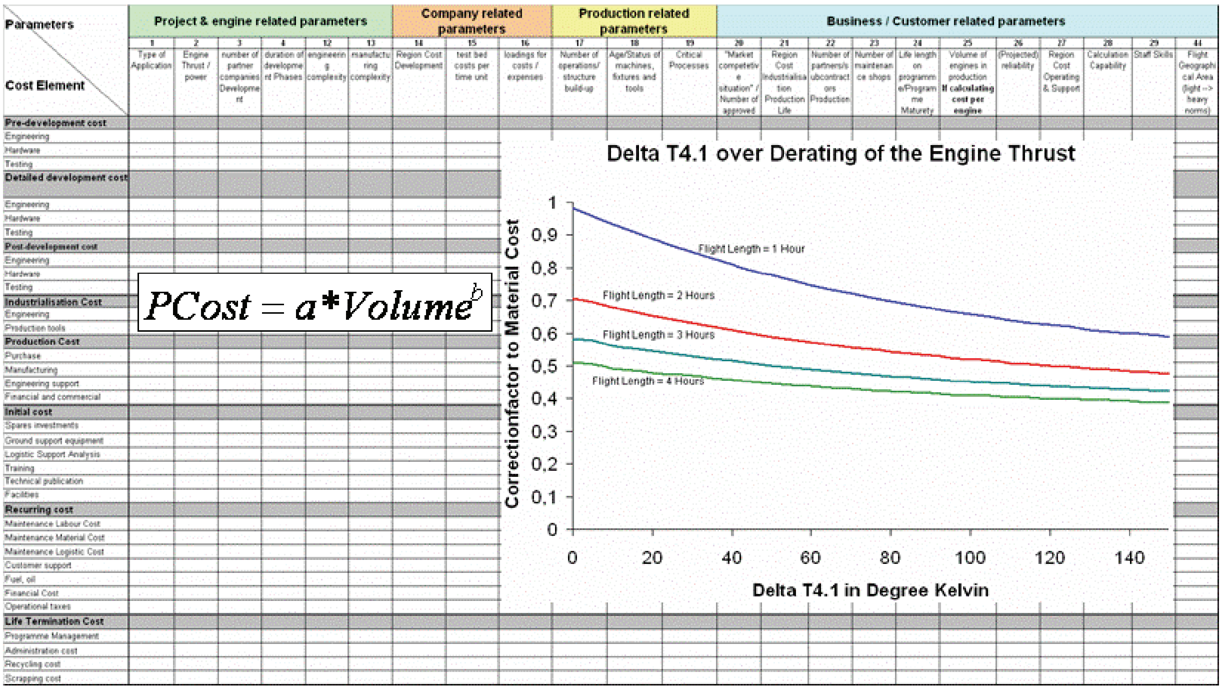


Figure 34: Sample of Dependency Matrix. (No influence appears because this is restricted to workpackage partners)

The Matrix is set-up in a Tool that may be used in early phases of a new project for a decision process. This enables vision of where the major impacts are likely to occur.

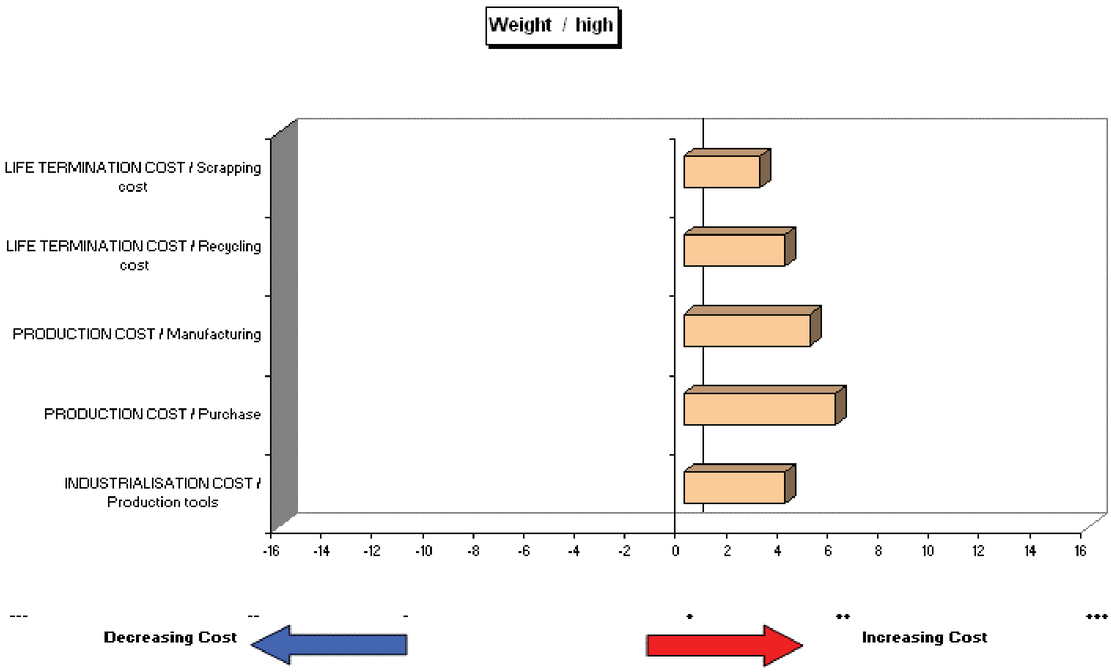


Figure 35: Sample of which Cost will be influenced by a high weight of the Product.

One of the major benefits of the agreements is to be in the possibility to react early in the development phase and give advice for design changes having identified critical areas.

The well-known picture below shows that most of the costs of a new Aero Engine are committed very early in the Life Cycle Phase.

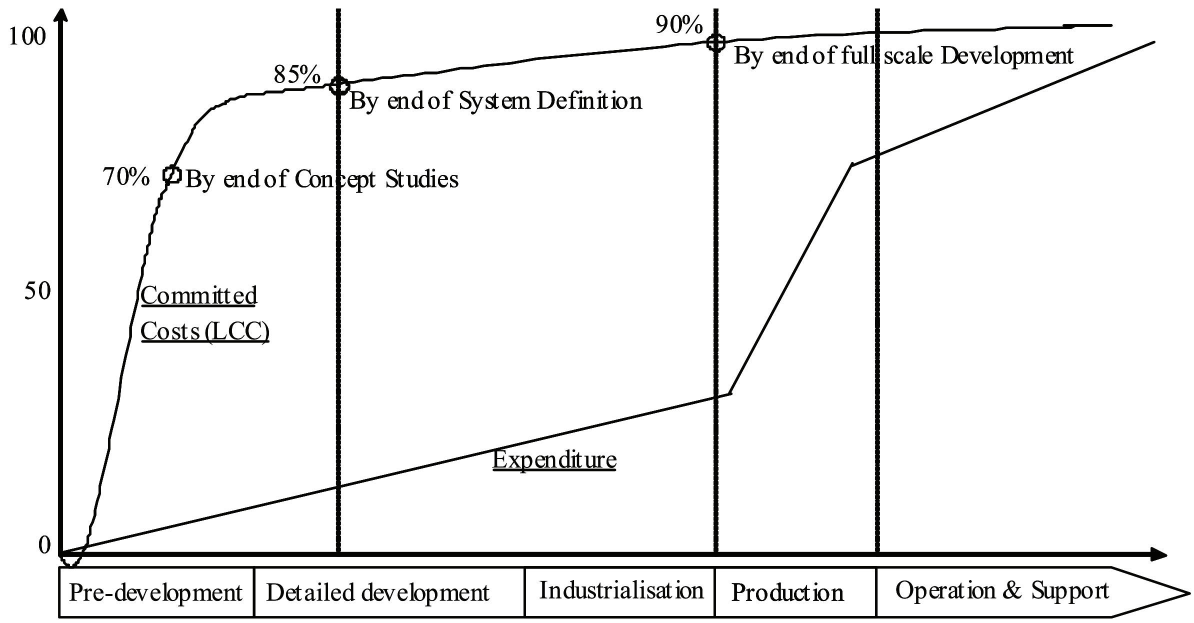


Figure 36: LCC committed costs vs. expenditure

With a Test Business Scenario, the Life Cycle Cost Model has been validated.

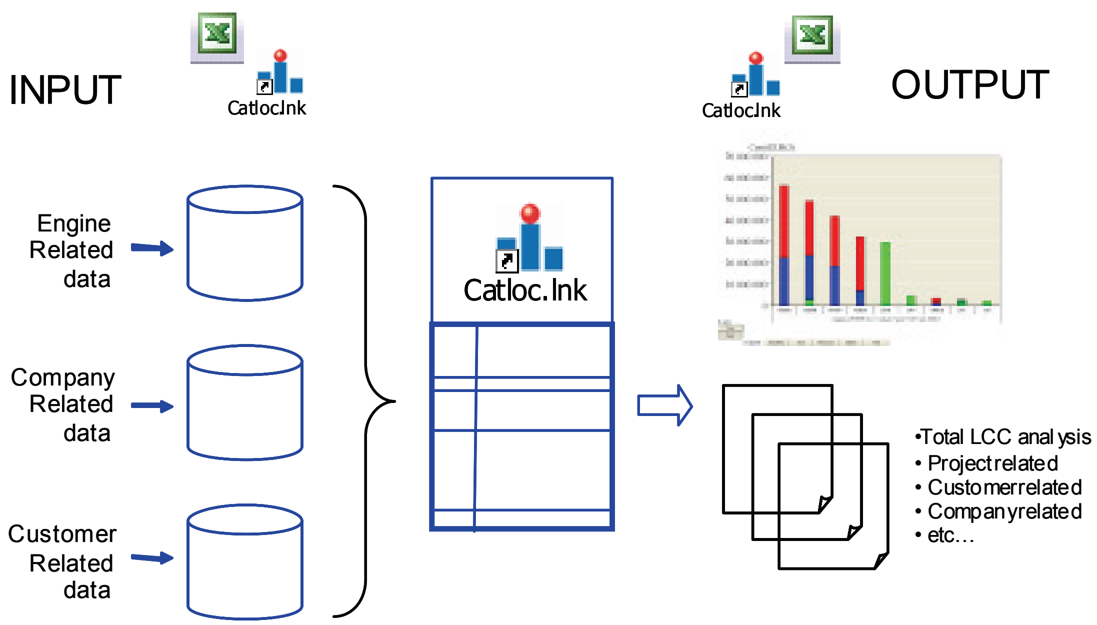


Figure 37: Data flow overview

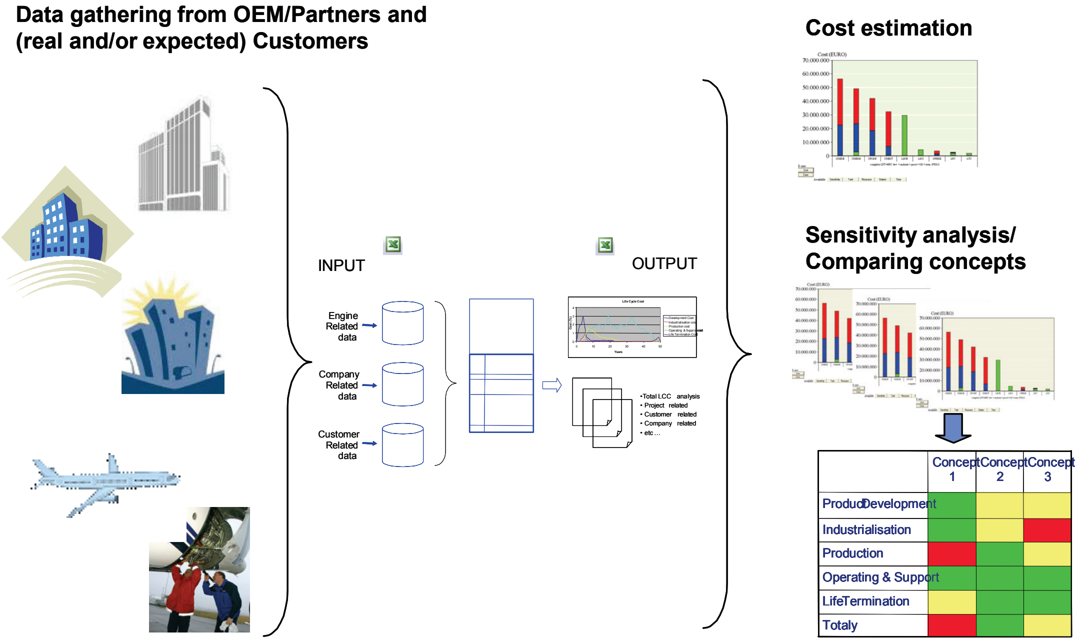
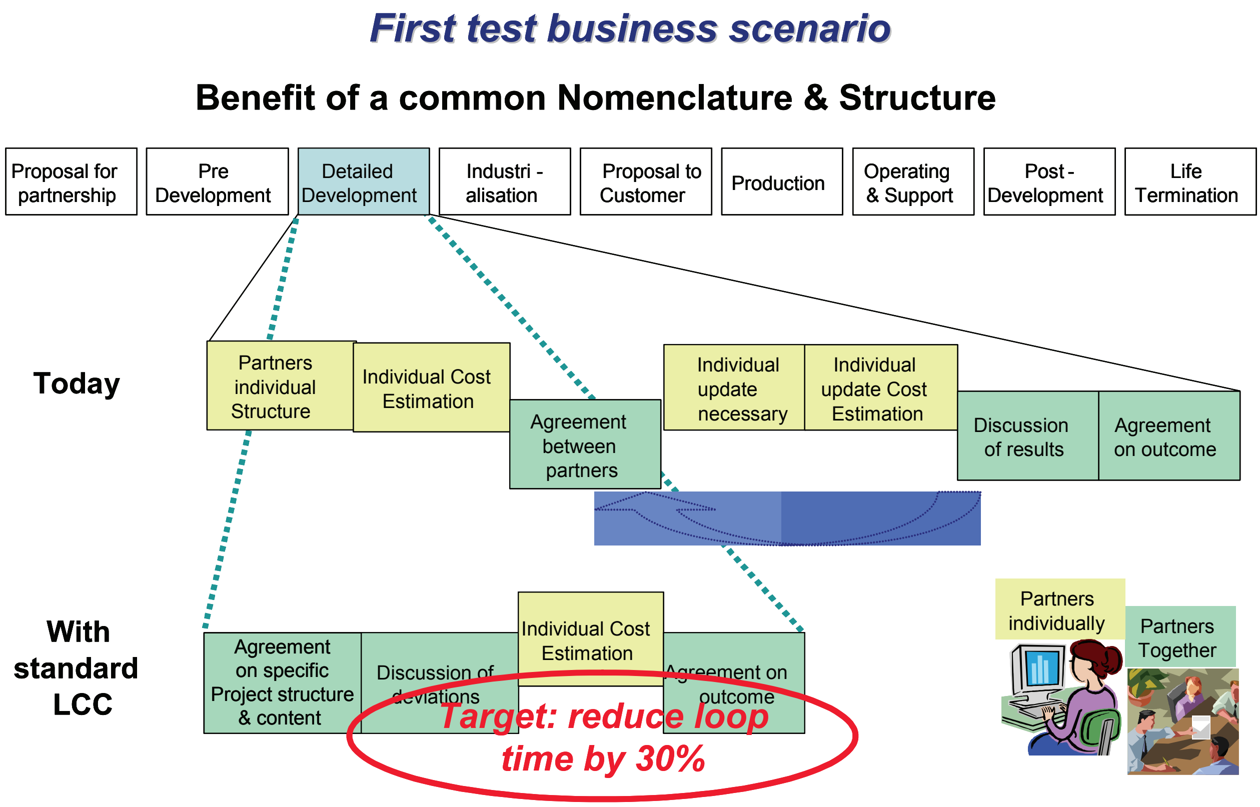
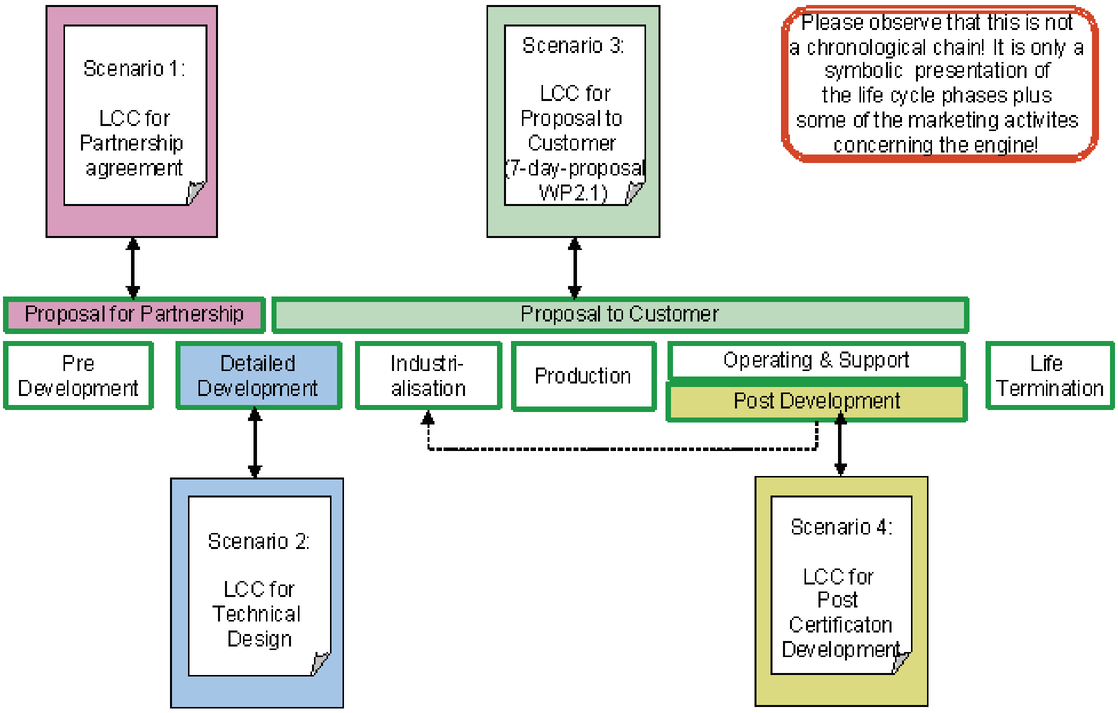


Figure 38: Data flow validation scenario

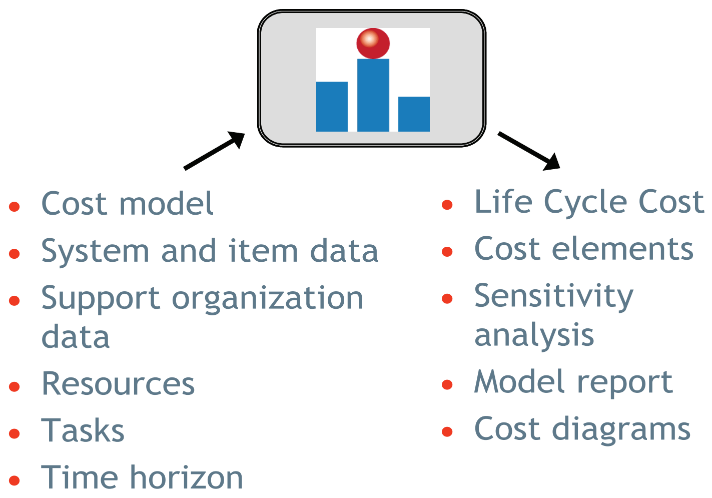
The following picture shows one possible case to demonstrate how Standardised European Life Cycle Cost Modelling will contribute to the overall VIVACE Objectives.



The Demonstration may be conducted by different Scenarios:



A User Interface has been selected which gives several capabilities such as build up specific structure, programming own mathematical algorithms, offering links to libraries (customer data, engine data, business data), etc.



Each of the participating partners brought in their specific knowledge for programming the Cost Estimating Relationships to each of the cost data element.

Cost Estimation Relationships have been developed on Level 4 and deeper (green squares) and being aggregated via Level 3 (yellow squares), Level 2 and 1 to Level 0 (red squares).

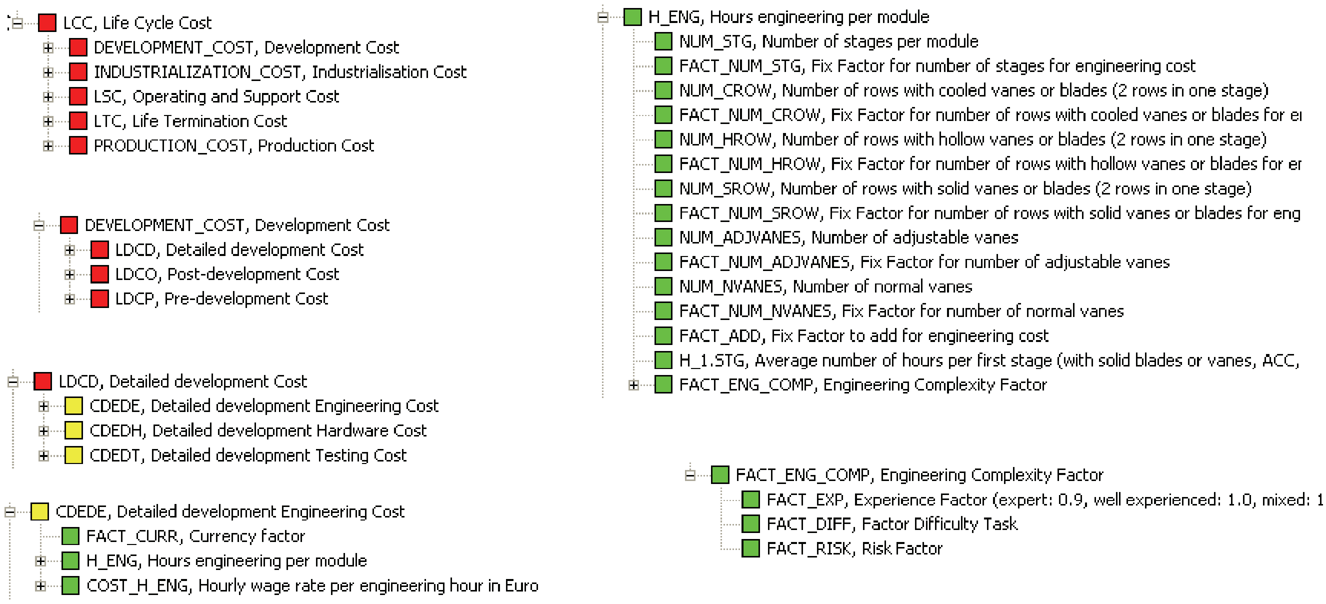


Figure 39: Cost Estimation Relationships.

There are several outputs possible (Pie Graph, Bar Graph and Reports):

- Results can be exported for further on calculations.
- The results can be created at Programme, Engine or Module Level as shown below.

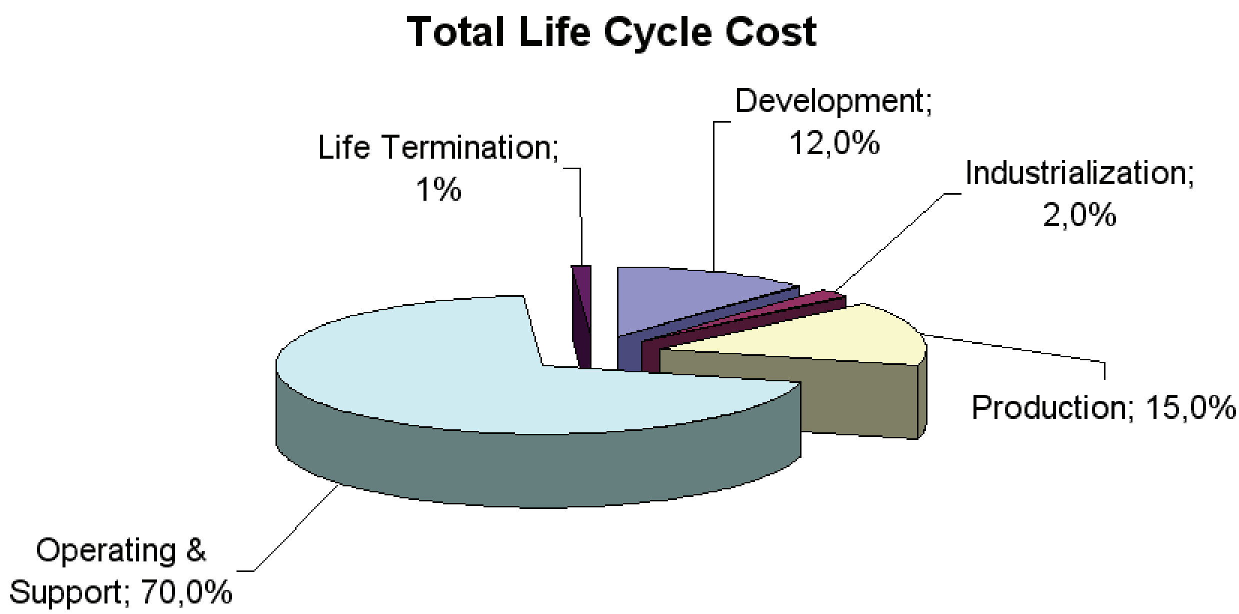


Figure 40: Sample of Cost Distribution at Programme Level.

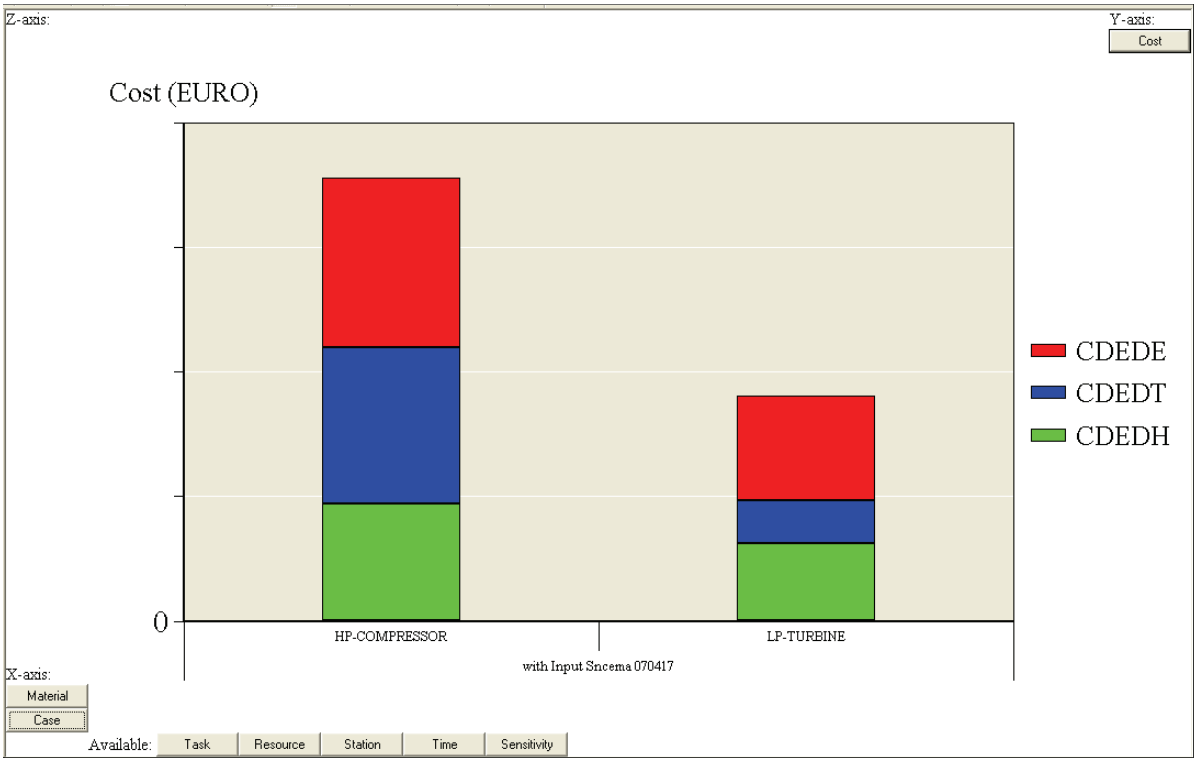


Figure 41: Sample of Cost Distribution at Module Level.

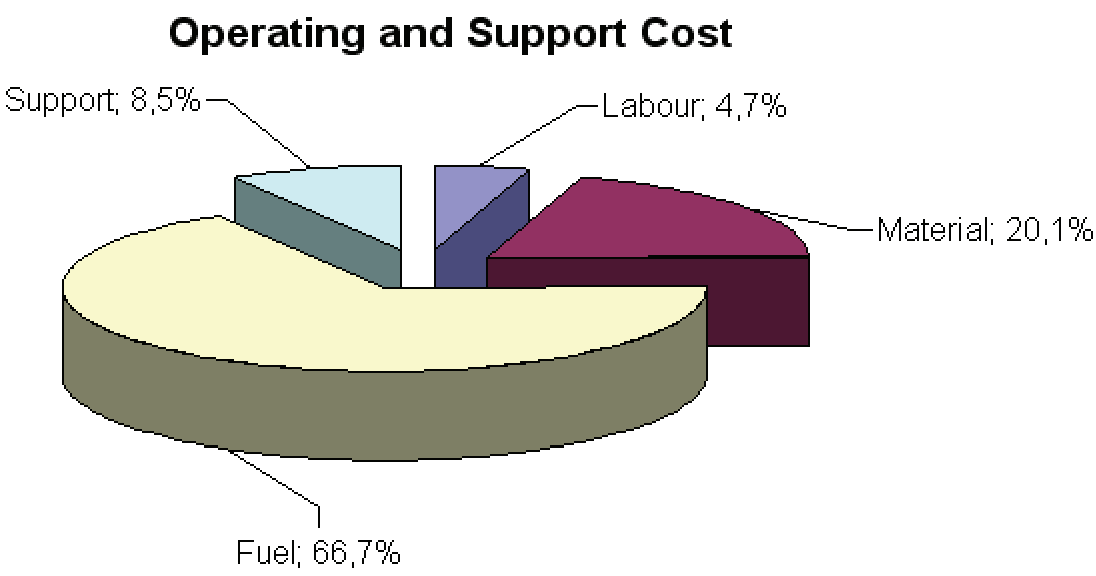


Figure 42: Sample of Cost Distribution on Operating & Support.

Whole Engine Development

► BACKGROUND

The Whole Engine Development work package supports the ACARE aim of *increasing European competitiveness* by co-ordinating the development, industrial implementation and partner integration of key state-of-the-art processes and technologies for mechanical simulation and collaboration.

- Modern airframe and engine development programmes increasingly rely on advanced numerical models to support competitive engineering design processes. Well-implemented simulation offers an effective understanding of the product behaviour. This is especially vital in the preliminary design stage in support of major engine architecture decisions. In the detailed design stage simulation strengthens the confidence of whole engine and component fitness for purpose, and provides a platform for robust validation backed up by physical testing.
- Engine development programmes involve a large number of partners, suppliers and contractors. Effective engineering design collaboration improves the speed of design decisions. This is important both within a single large partner organisation and between different participants in the programme and applied to all stages of the design process.
- A mechanical model of the whole engine is used to assess the effects of flight loads, temperature, vibration, rotor-dynamics and transient events. The engine integrator, working in close co-operation with the component design partners, assembles this sub-system model. Key outputs are casing stiffness, rotor tip clearance, loads distribution, critical speeds and rotor out-of-balance response.

► WHOLE ENGINE DEVELOPMENT

The Whole Engine Development work package is the practical realisation of the Virtual Engine concept. In this vision the model is created from the first definition of the geometry and includes all of the boundary conditions, constraints and thermo-mechanical duty that completes its definition; whole engine air system and thermal models are incorporated. This theoretical model then becomes the physical understanding of the behaviour of the engine.

The schematic picture below illustrates the key relationships between the whole engine model, component models and physical test during the engineering design programme. These link to the airframers model to form the integrated Virtual Aircraft model.

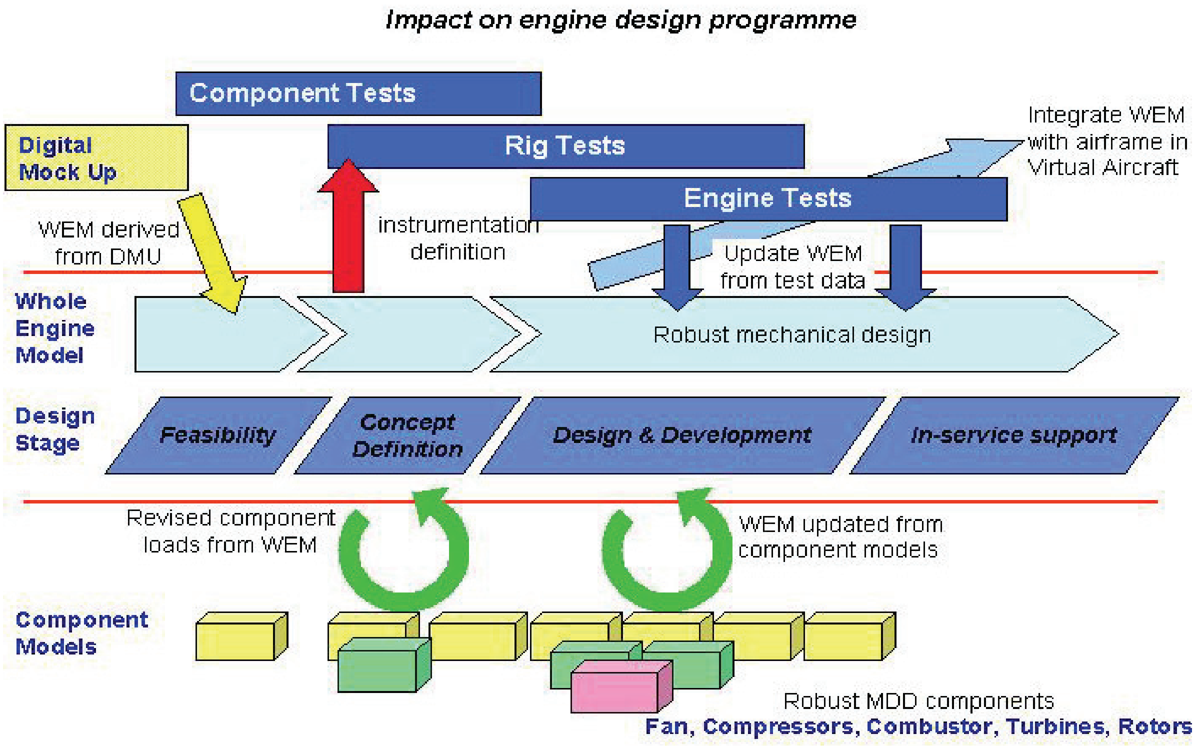


Figure 43: Impact on engine design programme

The ability of the whole engine model to influence the overall design at the Concept Definition stage relies on being able to model, analyse, assess and re-assess design scenarios very quickly.

Engine component partners rely on the whole engine model to supply tip clearances and interface loads for static and transient conditions. Detailed design depends on these being available quickly and accurately. A crucial issue is timely maintenance of the whole engine model as the detailed component design evolves – essential for understanding changes to component interactions and boundary conditions.

The whole engine model provides insight into the expectations of physical test, improving the test design and improving the usefulness and timely application of the acquired information.

The whole engine model plays a crucial role in understanding engine to airframe interaction – potentially influencing the wing and pylon design parameters.

The whole engine model (WEM) is assessed for flight loads, vibration, rotor-dynamics and transients using a common finite element description assembled between partners. Key outputs are casing stiffness, rotor tip clearance, loads distribution, critical speeds and rotor out-of-balance response.

The Whole Engine Development work package focuses on the following five themes:

- Whole engine preliminary model direct from the 3D digital design:

  The current industrial practice is to create shell and beam models, idealised from the 2D cross section and geometrical properties of the structural struts. These models are small and very fast to compute, but their creation is highly time consuming and require skilled users to be accurate. CAD packages have sufficiently progressed so that 3D solid geometries are available early in the process. The methods developed in VIVACE aim at providing tools and methodologies to derive from an arbitrary geometry a finite element model suitable for the whole engine model.

- Strong links between analysis and physical measurement:

  Physical testing must provide a reliable platform to validate and further refine our simulation techniques. Ever increasing time and cost constraints call for optimised testing where the right data is captured “first time”. Such optimisation can only be achieved if test and simulation work together and fully complement each other.

  Furthermore, an optimised test must make use of the latest advances in measurement methods (e.g. full-field LASER techniques), which provide a wealth of quality data in a short period of time. However, the distinct cylindrical shape of most aeroengine components will require modifications of these measurement techniques for their full exploitation in the whole engine model validation process.

- Automated whole engine model management through the design cycle:

  This implements new methods with latest technologies to more automatically manage the whole engine model through the design cycle, in close synchronisation with major component design changes, being developed concurrently – some in partner companies. This promises substantial process time reductions at consistent or higher levels of analysis quality, enabling timely assessment of engine sub-system and component interactions.

- Broader application of robust design practice:

  Robust mechanical design methodologies should be readily available for use with any analysis tools, design objectives and computing systems. This theme of Whole Engine Development has researched what tools are currently available and is in the process of applying them to today’s best practice analysis techniques, from several of the Industrial Partners.

- Robust processes for parametric component design:

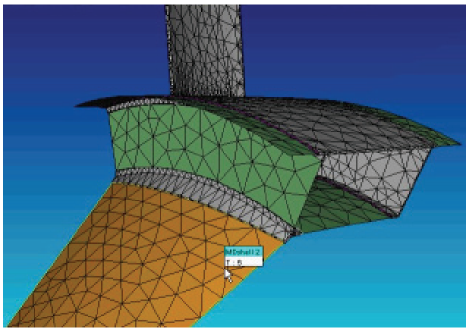
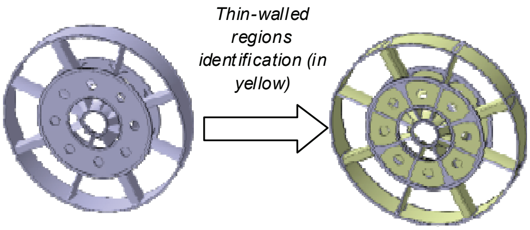
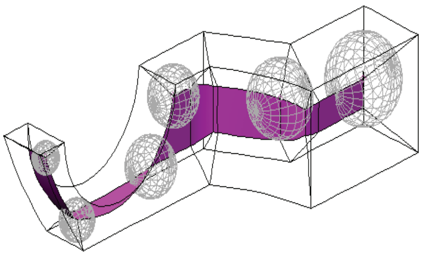
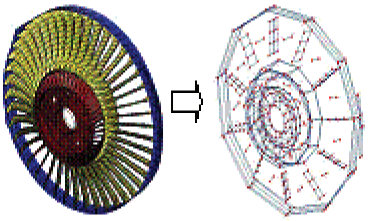
  Frequently, large design projects require the collaboration of several companies, which combine their specific skills and tools in order to pursue a common goal. In this manner the partners share risks and rewards of their activity, and adapt their own business and experience. This theme addresses some practical problems occurring within a collaborative design environment. These are the uncertainty of the design parameters, difficulty of integrating the analysis models, the execution time issues and so on. Over the last few years the robustness of the design procedure has gained more and more importance, in the presence of fierce competition which industrial companies must face.

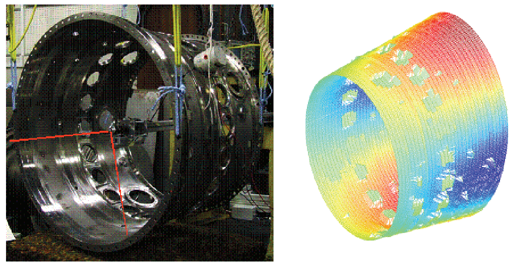
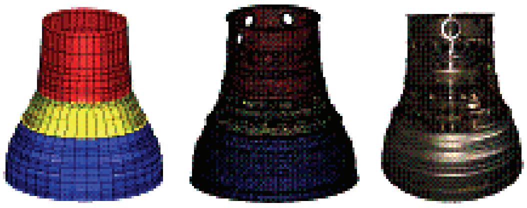
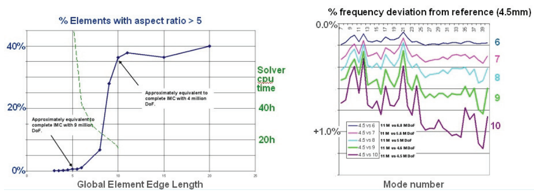
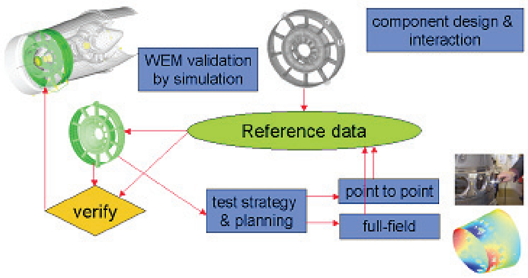
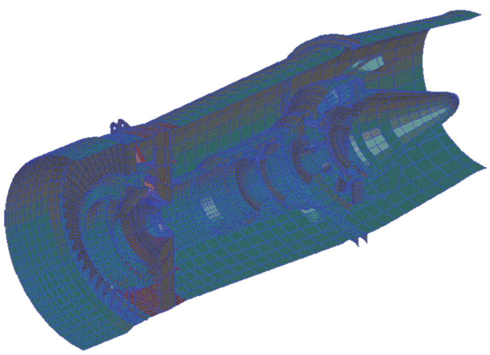
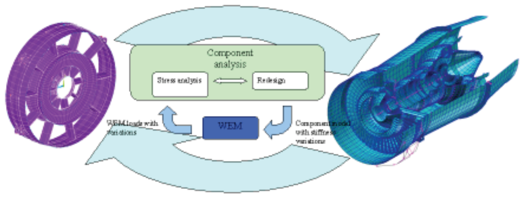
The commitment is supported by close involvement of major European aero-engine partners – Rolls-Royce, Snecma, MTU, Avio, Volvo-Aero, ITP – together with leading Universities, Research Institutes, CAE suppliers and engineering services suppliers.

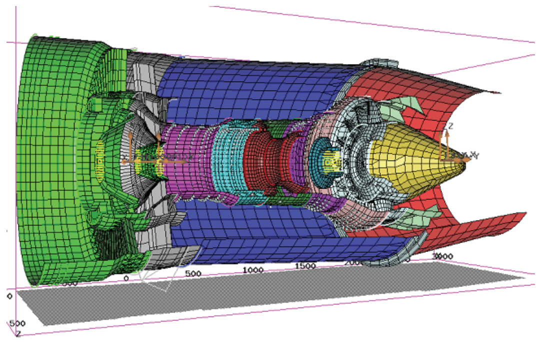
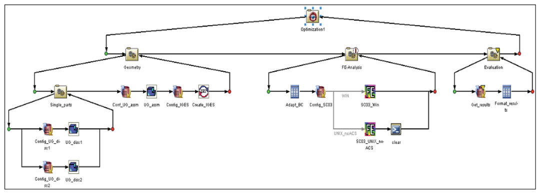
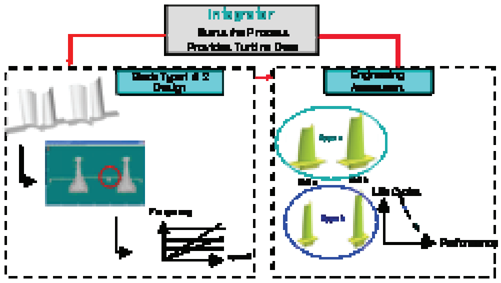
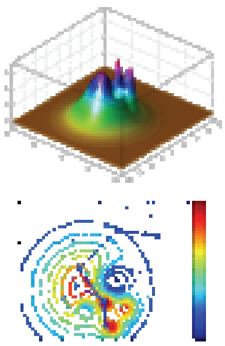
The implementation is strengthened by close links to the VIVACE Advanced Capabilities work packages: Multi-Disciplinary Optimisation, Collaboration Hub for Heterogeneous Enterprises, Knowledge Management, and Engineering Data Management.

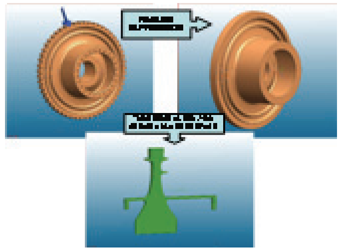
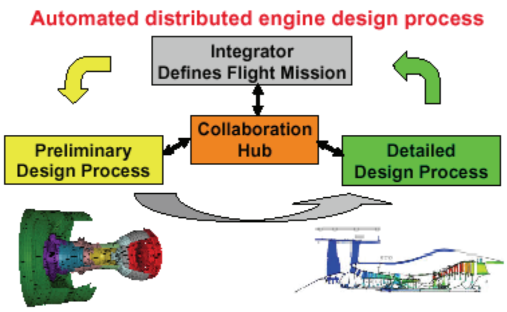
These will significantly contribute to the overall aims of 30% reduction in engine lead-time and 50% reduction in engine development cost.

▶ ACHIEVEMENTS

Achievement	Benefit	Example from use case
Automated mixed dimensional modelling of casing sector.	A mixed-dimensional (shell and volume) model can be automatically generated from geometry. Mixed-dimensional modelling had been previously constructed manually and was time consuming.	
Release of a thin-thick subdivision software module.	This software module partitions a solid geometry into regions suitable or not to be represented by shell elements, to lower model size.	
Robustness improvement of the medial object (MO) technology.	The underlying technology for the thin-thick module is the medial object (MO). Its robustness improved through the project, and allows the processing of complex geometries.	
Vibration test of real engine components and assembly.	Provides real industry examples of hardware to (1) increase the robustness of newer test strategy tools (2) provide reference response data to validate the emerging simulation based methods.	
Simulation tools for test optimisation validated and rolled out for production application.	Testing cost and timescales reduced by 30% during the first production application of this technology for design model validation.	

Achievement	Benefit	Example from use case
New capability for the measurement of the dynamic properties of aeroengine casings using LASER technology validated on a real component.	Unprecedented levels of quality and quantity of data for the validation of simulation models.	
Supermodel based design model validation technology demonstrated on a production application.	Component models validated ahead of manufacture. Excellent agreement with physical test results.	
Fit-for-purpose guidelines for supermodel generation.	Improved level of trust for using supermodels to provide a virtual reference response.	
Whole engine model, component assembly and validation process linked to collaboration hub (prototype).	Faster component design assessment. Timely maintenance of whole engine model for the partner-integrator design process.	
Multi-company, multi-component robust design process.	An iterative robust design methodology has been developed that uses whole engine model loads to improve component design at partner companies.	
Whole engine to component partner response surface mapping.	Reduces the need to exchange and interpret many thousands of results sets.	

Achievement	Benefit	Example from use case
Tools and processes that have been applied to the VIVACE whole engine model for assessing engine casing design effects on tip clearances and structural load distribution.	Assessment is being carried out simultaneously on two different Rolls-Royce production engines. This will enable tools and processes to be used on a new engine designs soon after VIVACE.	
Multi-company, multi-component linked robust design process.	Distributed robust design framework automates the distributed analysis process.	
Multi-company, multi-component robust design process.	A linked whole engine model and component robust design methodology has been developed, which used intermediate casing loads from the WEM to further improve the intermediate casing design.	
Successful demonstration in sharing geometry and analysis data.	This work has been further expanded and has been linked to one partner assessment of blade design and another partner assessment of an HP Turbine disc with each analysis providing inputs to the other.	
Important experiences and solutions collected in the treatment of stochastic variation of design variables and uncertainties affecting the multi-disciplinary design process.	Design and analysis process integration and automation into a "single functional whole" has been achieved. This capability allows time and cost reduction and it is mandatory for developing robust and optimised components.	

Achievement	Benefit	Example from use case
CAD based context model management: definition of the process to derive context models from 3D master model of a component and to manage the information coming from 3D models.	Easy re-use of modelling related knowledge captured in the master definition, in order to derive disciplinary models and to define an integrated environment that drives the creation of the context models needed in the multi-disciplinary robust design process. It supports the capture and re-use of design intent to increase design speed and productivity while intelligently controlling change propagation.	
Common approach for mapping engine design process.	Innovative solutions for exchanging stochastic data among different partners and discipline domains of engine's components design in a collaborative process. Links to CAD, CAE and collaboration tools at multiple design stages.	

▶ WHAT NEXT?

Airframe and powerplant integration

The whole engine model plays a crucial role in understanding engine to airframe interaction – potentially influencing the wing and pylon design parameters. The coupling between the powerplant, nacelle, pylon, wing and airframe body needs to be designed to maintain acceptable levels of performance, vibration and noise etc. during normal operation. Thermal effects of the powerplant system on accessories need to be managed. Sizing of the sub-system is influenced by loads and vibration transients due to extreme events. Whilst there always needs to be strong attention on the *components* of the system, an integrated system-level approach to the consequence of these effects provides an opportunity for improved overall design and the competitiveness of the aircraft.

- Current practice fails to maximise the benefits from a complementary system view.
- There are substantial logistical challenges to managing multiple models across sub-system suppliers and operating an integrated view.
- Sub-system interface definitions need to be precise, quickly defined and maintainable.

Preliminary design

Preliminary design of powerplant components follows decisions on overall architecture, arising from performance, cost and efficiency needs. Flow aspects drive the engine gas path design, integrity aspects drive the powerplant structural design. The mechanical and aero-thermal design is driven from both a top down (system level) view and bottom up (component level) view. The preliminary design stage brings these together into a whole powerplant definition, sufficient for individual component owners and powerplant integrator to proceed to detailed design, in cooperation with the airframer.

- A single-to-single discipline approach restricts shortening of time scales.
- Deterministic assessment may overlook the sensitivity to off-design behaviour or changes in the requirement. The can result in significant re-work at a later stage of design with the consequent impact on cost.
- The scope for simulation is limited by the elapsed time for modelling and the significant manual effort needed.
- The frequently used linear behaviour model limits the understanding obtained by simulation and increases the scope for later surprises.
- Interactions at system level (nacelle, pylon, wing, airframe) need representing.

Virtual and physical testing

Increasing and earlier reliance on simulation models of the powerplant, coupled with emphasis on automation requires a modified approach to the process for design validation. Physical test provides a tangible reference to prove the design, however this is usually available only after component manufacture. This together with practical limitations of physical test exposes us to the risk of significant unplanned cost to remedy unexpected findings.

VIVACE has demonstrated the use of mechanical simulation to provide reference behaviour models against which other design models may be validated. VIVACE has also advanced physical testing strategy. These two provide complementary roles for design validation.

This needs to be taken further, to cover assemblies, sub-systems, systems and cross-discipline activities. Validation of non-linear behaviour needs developing.

- Validation needs to be linked to fitness-for-purpose. This combines knowledge, criteria and automation.
- Variability associated with manufacture, materials, service loads and assemblies influences the way the virtual reference is deployed.
- Assumptions used in the virtual model need to be checked against the knowledge accrued through physical testing and in-service experience on similar components.
- Physical testing needs to be focused and aligned to requirements for verifying the virtual validation process as well as behaviour analysis.

European Cycle Program: PROOSIS: A shared gas turbine performance tool

The European gas turbine industry is a leader in the Research and Development (R&D) of advanced gas turbine engines, both for aircraft propulsion and land and sea based applications. The high level of complexity of modern gas turbine R&D programmes makes the technical and organisational challenges for European co-operative R&D anything but simple to overcome.

Traditionally, individual gas turbine manufacturers have developed their own simulation software. Consequently they have built up a legacy of engine and company specific simulation tools. This duplication of efforts could not have been avoided in the past due to the lack of clear standards and appropriate Information Communication Technologies (ICT) that enhance software development collaboration. Today, however, this situation is becoming unacceptable for the following reasons:

- The duplication of efforts to develop new simulation software technology and engine models is a waste of resources that will put the European gas turbine industry in an unfavourable competitive position;
- The incompatibility of simulation tools in European co-operative R&D programmes requires considerable effort to combine simulation tools from separate companies.

From these observations, it may be concluded that European industrial co-operation in the development of simulation tools is critical for the successful development of competitive gas turbine engines. The main objective of this work package is to develop a vehicle that facilitates the optimal use of R&D resources and smooth co-operation, especially in European co-operative programmes. A comprehensive, multi-disciplinary, object-oriented simulation environment has been proposed to integrate all European gas turbine simulation technologies into a single framework providing shared standards and methodologies for European universities, research institutes and companies. This simulation tool is named PROOSIS: **PR**opulsion **O**bject **O**riented **SI**mulation **S**oftware. "Proosis" is an ancient Greek word meaning "propulsion".

To become a standard simulation environment in Europe and maximise the benefits for gas turbine manufacturers, PROOSIS has been developed along four different themes:

- A user-friendly environment: PROOSIS considerably simplifies the construction, usage and management of models. PROOSIS also eases co-operative work by allowing partners to develop their models in-house and access each others' models as needed in a given project;
- The definition of a European standard interface makes data transfer easier between partners and reduces the scope for error;
- The creation of a standard library of components: PROOSIS is not only a communication system, it also provides a standard for gas turbine modelling in Europe and allows non-engine companies to have a common tool for jet engine simulation;
- The development of new tools: PROOSIS provides simulation capabilities that are not yet commonly available in the performance departments of European gas turbine

manufacturers. PROOSIS is adaptable enough to cope with different levels of component modelling.

Following a V cycle development process, PROOSIS software and the Standard Components Library (SCLIB) have been developed and validated. Two main types of validation have been defined:

- The first is related to the software: more than 300 unit tests have been defined to check the implementation of the individual user requirements. The majority of tests have been passed successfully. A shared web-site has been set-up to report and track bugs until they are corrected.
- The second is related to SCLIB: each component is tested individually, and the results are compared to in-house tools to validate the component modelling. The different versions of component modelling are managed and shared thanks to the “extended and virtual enterprise” hub. Two specific engines have been created to validate the integration of components. The behaviour of these models is satisfactory compared to reference models.

Following the delivery of several prototype versions, the BETA version of PROOSIS was delivered at the end of June 2007, to allow 6 months for final validation.

The BETA version offers a very user-friendly interface, allowing the user to perform typical performance calculations such as engine architecture building, multi-point design, steady point calculations, parametric studies, and transient working lines. The core of the tool relies on a symbolic equation sorting algorithm and powerful mathematical solvers allowing discrete as well as continuous event management.

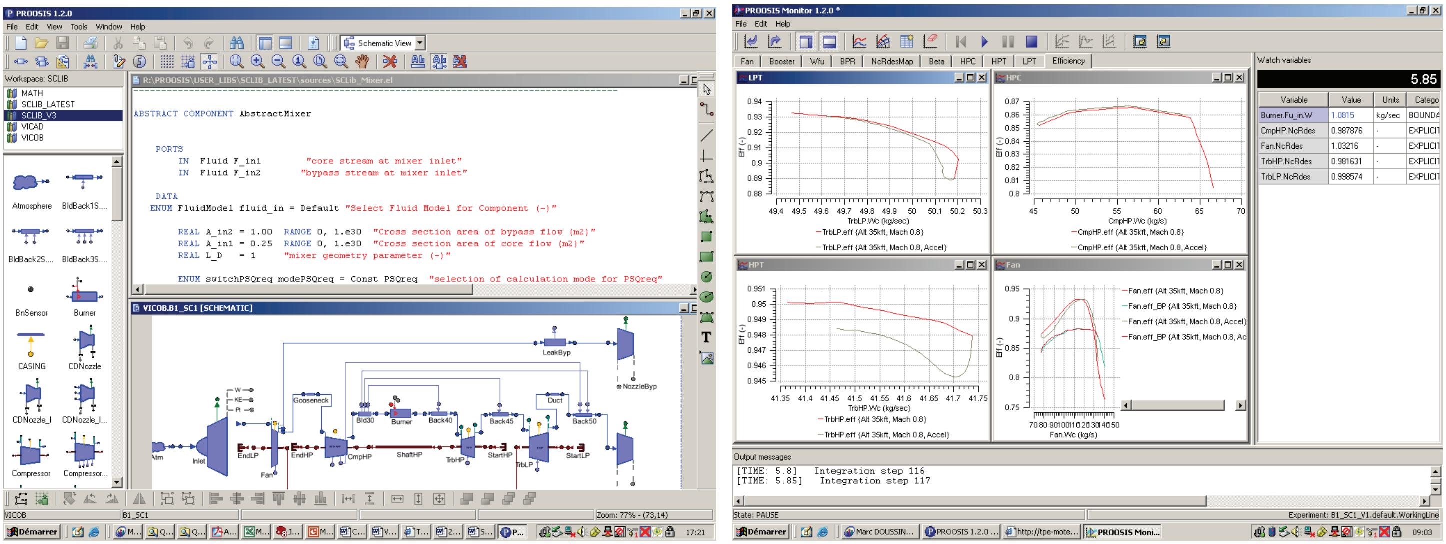


Figure 44: PROOSIS graphical user interface

In the left part of Figure 44, from top left to bottom right, one can see relevant existing libraries, some components of the developed standard gas turbine library, a typical window for component developers, and the engine model window where one can drag and drop components from the library and link them together. In the right part of the figure, one can see the simulation interface where plots can be drawn, the component map can be visualised and the results can be edited in table format.

PROOSIS is not only a "stand alone" tool. In the "advanced capabilities" part of the work, it has been demonstrated that PROOSIS is an open tool which can be easily linked to external tools:

- To build and run an engine model using a distant component. As an example, NLR has built an engine model in which the compressor part is run at The National Technical University of Athens. If the compressor modelling is simple (no zooming, or 1 dimension zooming), there is no delay in the computation time. Thanks to this capability, all partners can keep their component modelling private and give access only for computation.
- To replace traditional "0 dimension" modelling by a more accurate one called "zooming". Several examples have been shown for fan, compressor and turbine components. Instead of using traditional "maps", which give the relation between rotational speed, mass flow, pressure ratio and efficiency through tables, a more representative model of mean line, or even 2 or 3 dimension fluid dynamics computation tools is used. Of course, with a fully coupled approach, the increased accuracy is counter balanced by an increase in computation time. To return to a reasonable computation time, de-coupled and semi-coupled approaches have been set up.

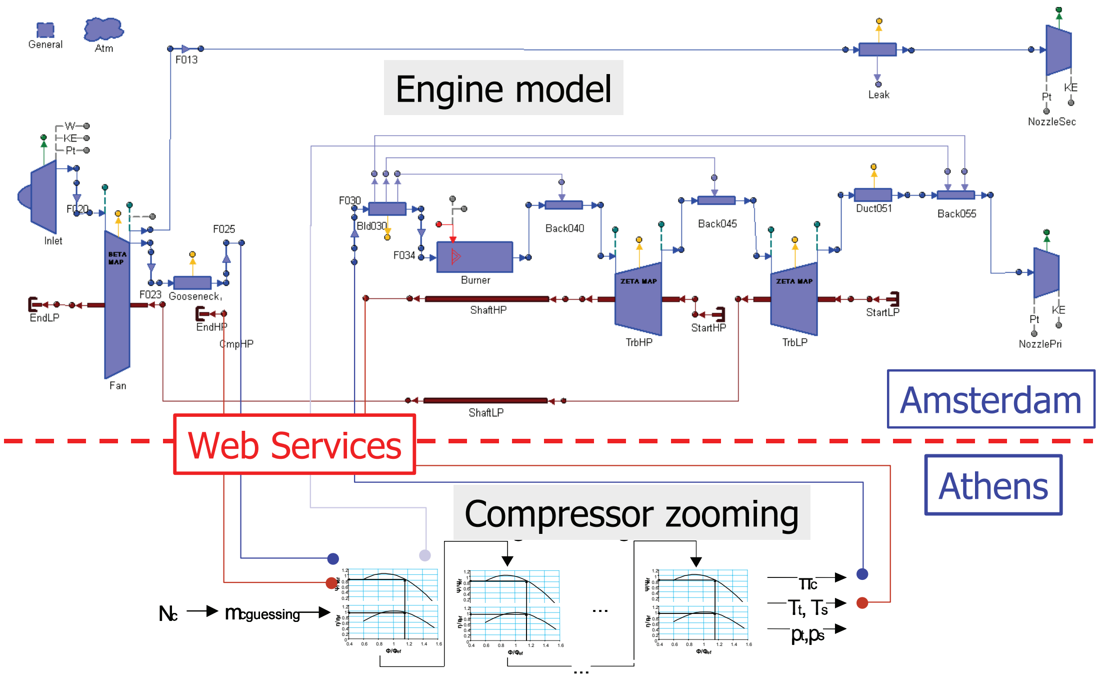


Figure 45: Compressor zooming and distributed architecture model

- To perform multidiscipline calculations. Even if thermodynamics is the core part of engine performance models, engine design involves many other disciplines such as heat transfer, aerodynamics, mechanics, and life potential. Two different solutions for multi-discipline coupling have been demonstrated. The first is to ask PROOSIS to call an external calculation chain: read geometry data, generate the meshing, generate boundary conditions from the mean thermodynamic conditions, perform the zooming calculation, and extract average values from the results to feedback into the engine performance model. The second is to use PROOSIS as a "brick" in a workflow process. In that case, PROOSIS output is used as the boundary condition for the next tool, and after one loop, PROOSIS boundary conditions are changed by the previous tool in the chain.

- To optimise the whole system. Once the model is coupled to different disciplines, it is necessary to link it to an optimisation tool. The multidiscipline optimisation has been demonstrated with two use cases. In the first one, the fan geometry has been optimised for efficiency with some constraints on the pressure ratio, geometry, mechanical stresses and mass flow. The second one deals with the optimisation of turbine disk geometry and bleedings in order to increase life potential. In this case, the optimisation uses the transient capabilities of the tool chain. One part of this work is done in collaboration with the Multi-Disciplinary Optimisation (MDO) work package.

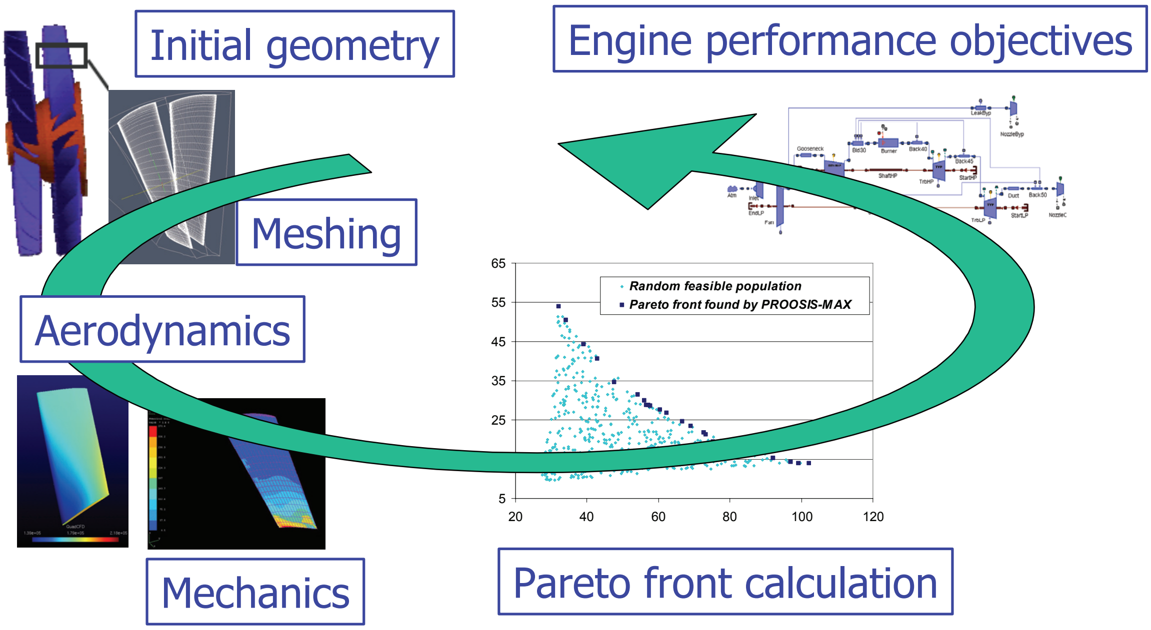


Figure 46: Fan blade multidiscipline optimisation

Thanks to VIVACE, the European gas turbine community has developed a common environment for engine performance simulation. PROOSIS is now ready to be deployed in the companies participating in the project. The benefits of using this common modelling and simulation environment have been quantified through different use cases. In particular:

- Integration time reduction: thanks to the defined standard modelling language and interface, it is now very quick and easy to integrate components from different partners in a single engine model. In the use case chosen for the demonstration, the time reduction is 50%.
- Cross checking reduction: the need of component integration checking is greatly reduced. In particular, the modelling of correction effects (bleeds, dissociations, etc.) is directly integrated in the engine model. Only one crosscheck is needed instead of three or four in the previous way of working.
- Accuracy increase: modelling translation is no longer needed to integrate components in the engine model. It is possible to use different component modelling in the same engine model (for example fan using BETA map and compressor using MFT map), and it is even possible to use company specific fluid models for each component. The impact of this flexibility is that the component integrated in the engine model is exactly the one

developed by the partner and that the resulting model is free from discrepancies due to modelling translation.

The core capabilities of PROOSIS are ready to be used by industrial partners. A consortium is being set-up to maintain and support the tool. PROOSIS has already been used for aircraft and helicopter engine modelling, but all kinds of gas turbines can be modelled with PROOSIS. For instance, a space rocket engine, with multi-stage H_2-O_2 combustion, has also been modelled with a specific component library.

It has been demonstrated that advanced capabilities are compatible with PROOSIS architecture. Specific prototypes of functions and interfaces have been developed to allow the connection between PROOSIS and external components and tools. However, this requires an important workload for the end-user, who must have some IT skills. The next step is to develop generic and context-oriented interfaces for advanced capabilities that would allow zooming in a component by a simple connection to a "discipline" object, or zooming back to whole airplane design parameters for engine integration and global noise level evaluation.

Supply Chain Manufacturing Workflow Simulation

Historically, hardware has been designed without much regard for its effect on the overall production process, including the supply chain and the subsequent effects on future business concepts. However, the production community has started to acknowledge the importance of the design of the supply chain in the hardware design process. This is especially important because the attributes of the supply chain have a significant impact on the possibility of successfully establishing competitive, next-generation systems that will reduce the cost of travel. The main objective of the work package is therefore to develop a new approach to product development, addressing logistic issues by modelling workflow within individual companies and the supply chain as a whole.

Work has been undertaken in four areas:

- The development of a tool for data-driven supply chain simulation, whereby models are constructed directly from information held within company ERP systems.
- The evaluation of alternative systems of logistic control, identifying their influence upon the performance of a business unit and upon the supply chain.
- The identification of cost-effective production process, fitting an individual company's production capabilities to product performance characteristics.
- The conceptual integration of these methods and tools.

The work in these areas is described in the sections that follow.

► Data driven Supply Chain Simulation

With increasingly complex supply chains, simulation has become a powerful tool to assess performance. The overall objectives of supply chain simulation are two-fold:

1) To define the key elements needed to describe a supply chain and capture its dynamic behaviour;
2) To establish techniques and develop methods to evaluate alternative supply chain concepts, seeking optimal supply chain effectiveness.

The first objective includes the description of:

- Relevant business environments in which the supply chains will function;
- Current and future business process requirements to facilitate relevant supply chain modelling;
- The underlying aeronautical supply chain structure;
- The need for, and formats of, supply chain information exchange within the extended enterprise;
- Relevant logistics concepts;
- Supply chain risk, robustness and resilience;
- A framework for measuring the efficiency of the supply chain in the simulation models;
- Supply chain modelling best practice.

Data-driven supply chain modelling and simulation techniques have been adopted to achieve the second objective. This approach facilitates a more effective way for fast changes in the simulation model when evaluating the effectiveness of a supply chain. In data-driven supply chain modelling and simulation, a model is constructed automatically by a software program, based on data existing in company IT systems. A model created in this way can be reconfigured rapidly, by changing the external data. Hence, a user could explore the implications of radical changes to a simulated extended enterprise, despite having little knowledge of the simulation software itself.

A prototype data-driven extended enterprise modeller and simulation builder has been developed. It automatically generates an Access database, a supply chain data model and an Arena simulation model. It can create models of large aerospace supply chains with all main supply chain control mechanisms and parameters. The model builder has been fully verified and validated, this being achieved via use cases from VIVACE partners. The model produced results exactly as expected.

This methodology is generic and applicable to all tiers.

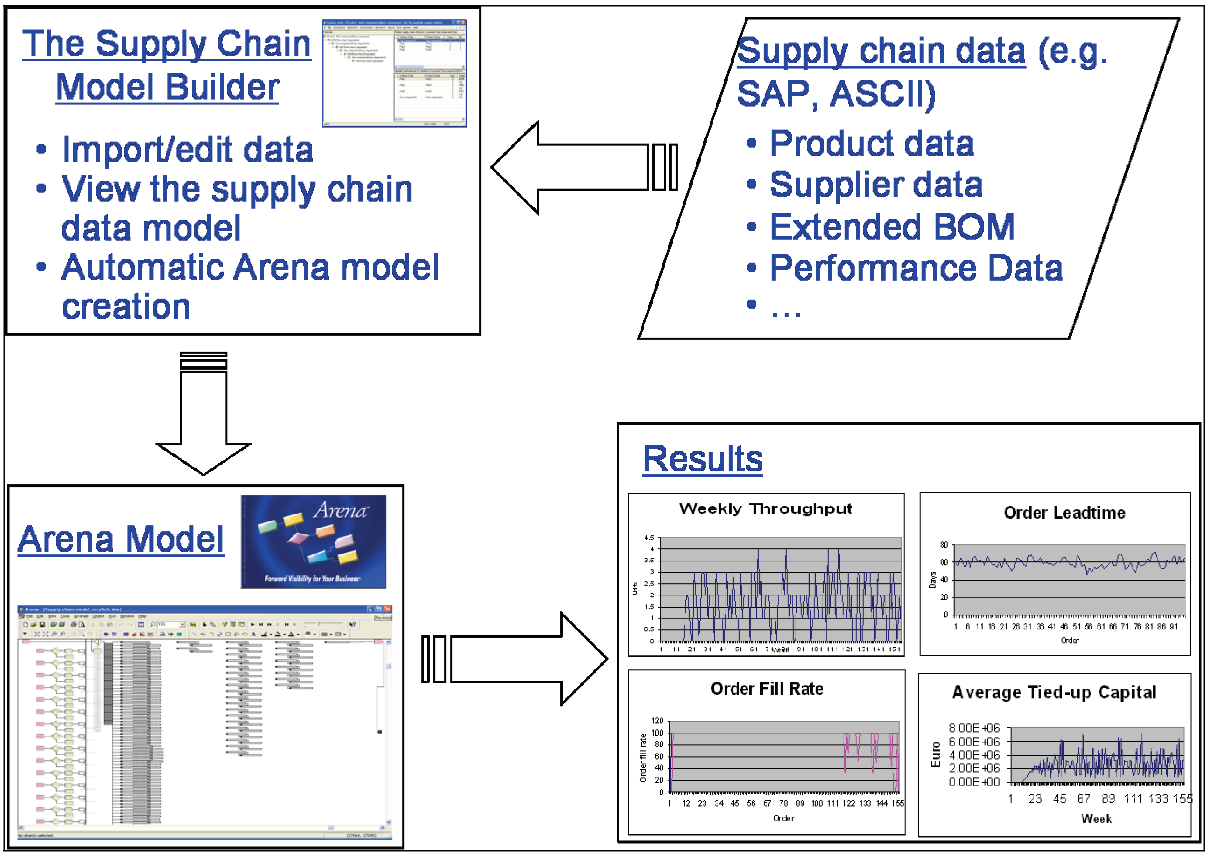


Figure 47: Data driven Supply Chain simulation

► LOGISTIC CONTROL CONCEPTS WITHIN THE COMPANY

This activity investigates the performance of the manufacturing system in terms of the workflow within a facility and its performance as a component of the supply chain. It was aimed, through simulation, to increase understanding of the production scheduling and control techniques that might be applied within partner companies. Simulation allows manufacturing system performance to be evaluated under various conditions, without disrupting real production operations, thus permitting opportunities for increased production effectiveness to be identified.

Being constructed from model elements developed during the project, it has been shown how a variety of logistic concepts can be applied to a facility model. Supported control methods include MRP-driven approaches, Kanban systems, OPT, Period Batch Control and a number of hybrids. In this way, simulation can support complex strategic decisions such as varying the product mix, or investing in new equipment.

Figure 48: Some of the logistic concepts evaluated, under a variety of deviation scenarios

A novel approach has been developed, whereby a single model can be used to simulate different logistic control principles, the parameters for each experiment being entered via a simple user interface. Model outputs are exported to a spreadsheet, and graphs showing the business unit's performance are generated automatically.

Three simulations have been constructed, each representing a facility at the partner companies. These diverse use cases test the approach being employed over a broad range of circumstances since one involves lengthy machining operations, low volumes and high-cost parts, one involves batch manufacture and the last concerns a facility where a very wide range of product types are processed; the success of these diverse models suggests that the approach could be applied within other businesses.

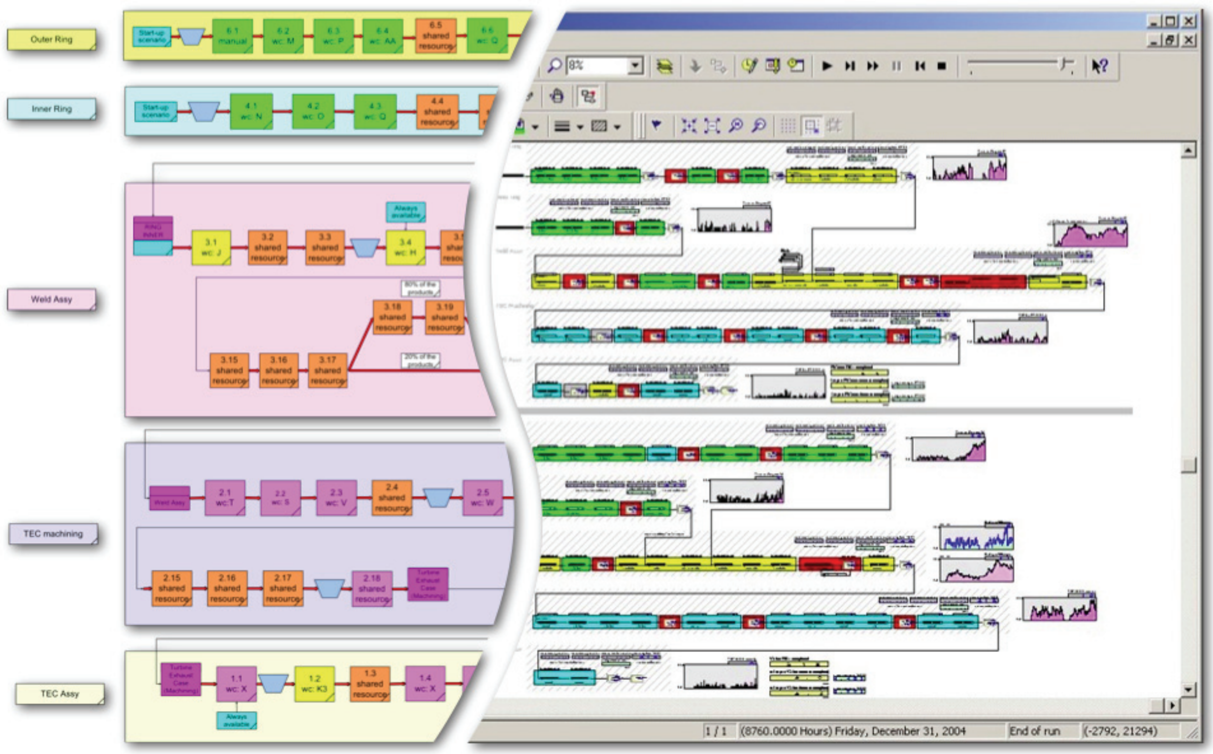


Figure 49: Facility model constructed using Arena from Rockwell Software

In each case study, validation was achieved through comparison with real-system performance, sensitivity analyses and detailed experimentation. In one instance, there was also a comparison between the case study model and an equivalent one generated by the supply chain model builder.

The resulting increased knowledge of how systems perform when governed by a variety of logistic control systems, together with a more efficient methodology for control within simulations, are key factors in making production units more efficient. This methodology is generic and applicable to all tiers in the supply chain.

► Methods and Tools for Workflow and Process Chain Evaluation

Process chain evaluation is undertaken in order to generate alternative production sequences, for assessment in terms of their monetary, functional and qualitative characteristics.

This ensures that the best overall process chain can be chosen.

The evaluation of process chains encompasses the generation and assessment of single processes within sequences, and the assessment of complete process chains. The scope of production process chain generation and evaluation also involves the identification of relevant requirements and objectives. Thus, the method for process chain evaluation must be defined in the company's standard work description, to guarantee the optimal workflow within product development and production planning.

A use case study was conducted, proposing a future method for production process chain generation and evaluation. This addressed not only the methodical approach, but also identified possible supporting software tools and existing approaches. Identified commercial software tools were evaluated for their suitability.

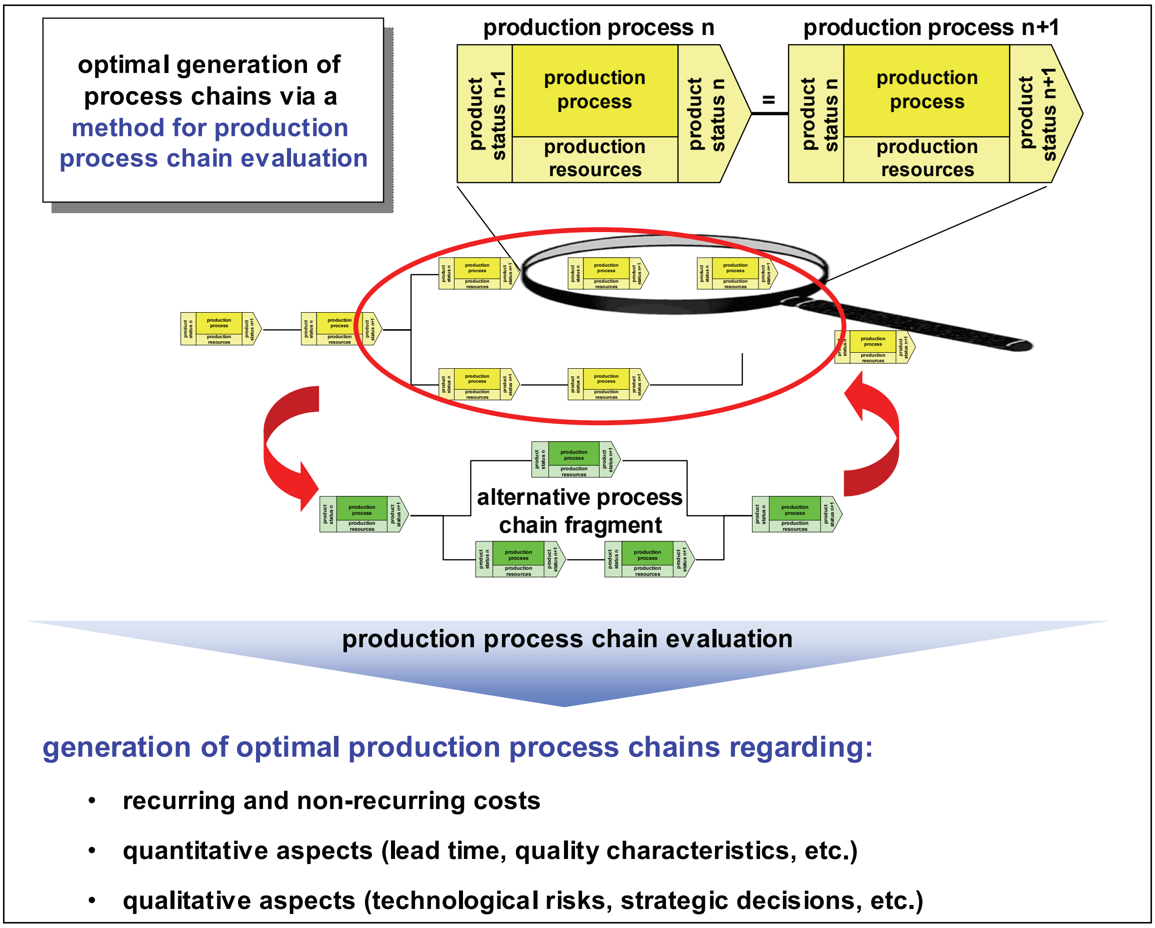


Figure 50: generation and evaluation of process chain

The method was validated using a test implementation with commercial software. It was shown to be usable in the intended production environment. The benefits of the method are tangible, in the form of more efficient process chains achieved for less engineering hours. A number of other benefits have also been identified, including improved knowledge management within the company, increased standardisation and a higher degree of transparency.

This methodology is generic and applicable to all tiers.

► Conceptual Integration of Tools and Methods

The methods and tools described are intended as different parts of a common modelling and planning system. The required data for each operation are assumed to be made available via an extended enterprise collaboration hub, and this functionality has been represented within the simulated supply chain environment.

A prototype website showcasing the e-business supported supply chain has been developed, showing relevant interactions and interfaces between data-driven supply chain simulation, internal logistics simulation and process chain evaluation.

► PROPOSED FURTHER WORK

The Supply Chain Model Builder technology is mature, and could now be used to analyse environmental impact of alternative supply chains, examining the total impact of outsourcing decisions, to facilitate the "green supply chain".

Common standards for logistic terminology and definitions could be further exploited to facilitate cooperation between partners (incl. 3rd tier suppliers) in the supply chain.

Advanced Capabilities – An Overview

As stated by the VIVACE partners at the beginning of the project in the VIVACE project summary:

"VIVACE will develop Advanced Capabilities (Knowledge Enabled Engineering, Multi-disciplinary Design and Optimisation, Design to Decision Objectives, Engineering Data Management, Distributed Information Systems Infrastructure for Large Enterprise and Collaboration Hub for Heterogeneous Enterprises) applied to real world engineering and business requirements from the aircraft and engine sectors. The main result of VIVACE will be an Aeronautical Collaborative Design Environment and associated processes, models and methods. This environment will help in designing aircraft and engines as a whole, providing virtual products with all requested functionality and components in each phase of the product engineering life cycle to the aeronautics supply chain in an extended enterprise."

At the end of this four year endeavour, this vision of an Aeronautical Collaborative Design Environment is now well defined as demonstrated at the VIVACE Forum 3. It is also referred to as the ***VIVACE Toolbox***, highlighting the fact that it is a re-usable result that will be exploited after the VIVACE project ends.

To understand the role of Advanced Capabilities in this environment, it is important to consider firstly the linkage of the VIVACE System with the business needs and with the actual implemented tools that VIVACE partners have modelled using the ***8-layer Model***, and secondly the way the Advanced Capabilities all contribute to the VIVACE Toolbox through a common ***Generic Service Architecture***.

The 8-layer model (see Figure 51), is a representation of the various aspects considered in the VIVACE project. VIVACE partners have identified this model as a valid representation to structure results from the technical activities conducted in the project. This model should not be considered as an architecture but as a segmentation (or taxonomy) of technical subjects handled in the project.

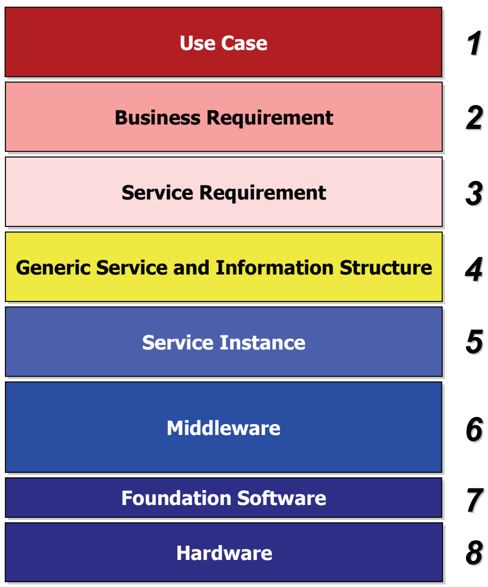


Figure 51: The 8-layer Model

The main advantage of this model is that it highlights the segmentation between level 4 (in yellow), which is the focus of the VIVACE System, and business issues (in red) and implementation issues (in blue). This shows that VIVACE results are not software tools but *generic services and information structure and standards* that are implemented and demonstrated using software tools.

All Advanced Capabilities contribute to level 4 of the 8-layer model by developing a set of *Generic Services* and to level 5 by implementing these Generic Services in software tools for validation and demonstration.

"Generic Services" should be understood as follows:

- Service means an aeronautical engineering IT capability, organised from an IT perspective using the "Service-Oriented Architecture" approach. It could be a service to retrieve knowledge elements in a specific aeronautical context, or a service to share and manage simulation models, as demonstrated during Forum 2 in late 2006. A service, by nature, is open to being used by several users, or Use Cases;
- Generic refers to the independence from any implementation: VIVACE Generic Services can be implemented on several IT infrastructures, using different commercial tools (in this sense "Generic" refers to the Model Driven Architecture from the Object Management Group).

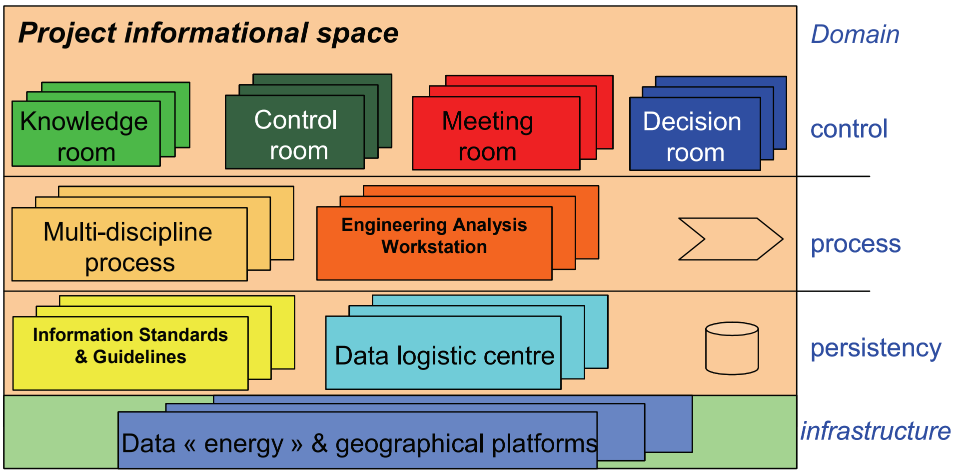


Figure 52: VIVACE Toolbox Capabilities architecture

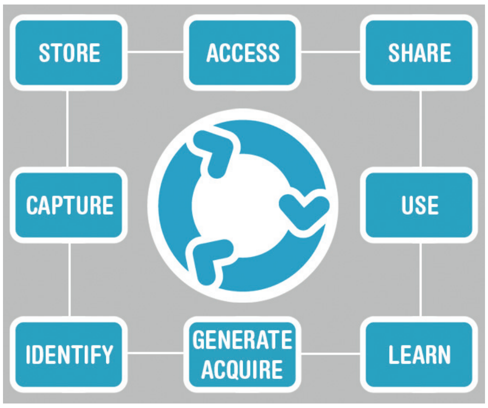
The Advanced Capabilities provide a set of services organised using a standard "4-tier architecture" as shown in Figure 52. The Forum 3 demonstrations showed the exploitation of this Toolbox through several use case scenarios. Depending on the specific needs of a collaboration (need to share knowledge, need to organise and trace the exchanged data, need to set-up multi-disciplinary processes, and so on), the Toolbox is used to build the right "Aeronautical Collaborative Design Environment" required to support the collaboration between teams in a Virtual/Extended Enterprise context. That is why, even if the Advanced Capabilities are described independently hereafter, it is important to keep in mind their linkage, as well as their global organisation as shown in Figure 52.

Knowledge Enabled Engineering

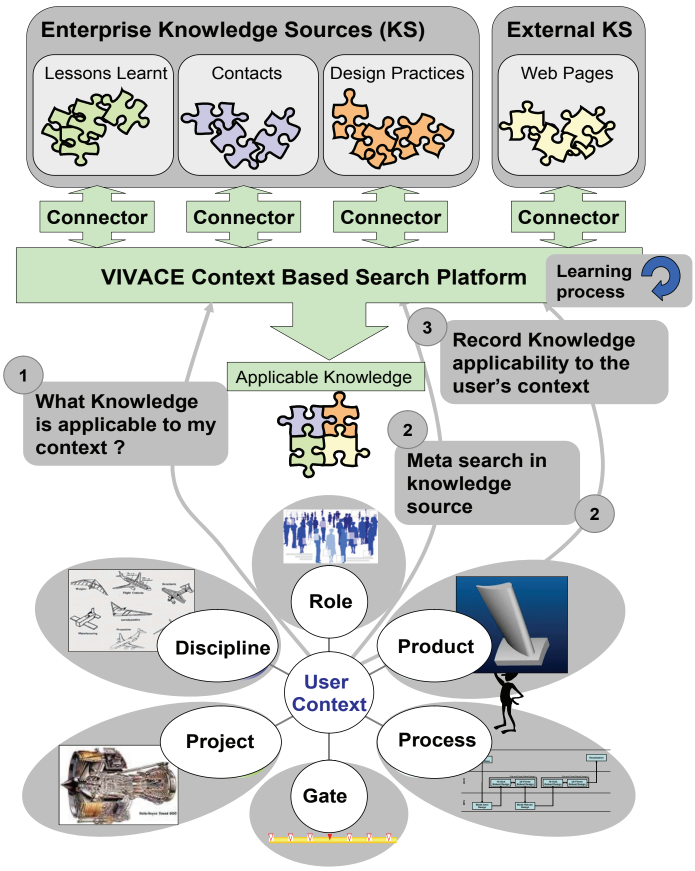
► Knowledge Enabled Engineering Background

Knowledge Enabled Engineering is the ongoing process through which an Enterprise uses its collective intelligence to reduce the duration and improve the robustness of strategic engineering activities.

The focus of the Knowledge Enabled Engineering activities carried out within **VIVACE** was on the different phases of the Knowledge Lifecycle. The main objective was to develop and exploit advanced software methods and guidelines that would improve the engineering process by leveraging past design experience and capturing how knowledge is used.



► Knowledge Enabled Engineering Solution



Achieving the aforesaid business objective meant dealing with the real problems that aerospace companies are facing within the knowledge domain. A common view put forward by contributors working in this field is that such problems cannot be solved by technology alone. Technology is merely an enabler, so consideration must also be given to the people and processes involved.

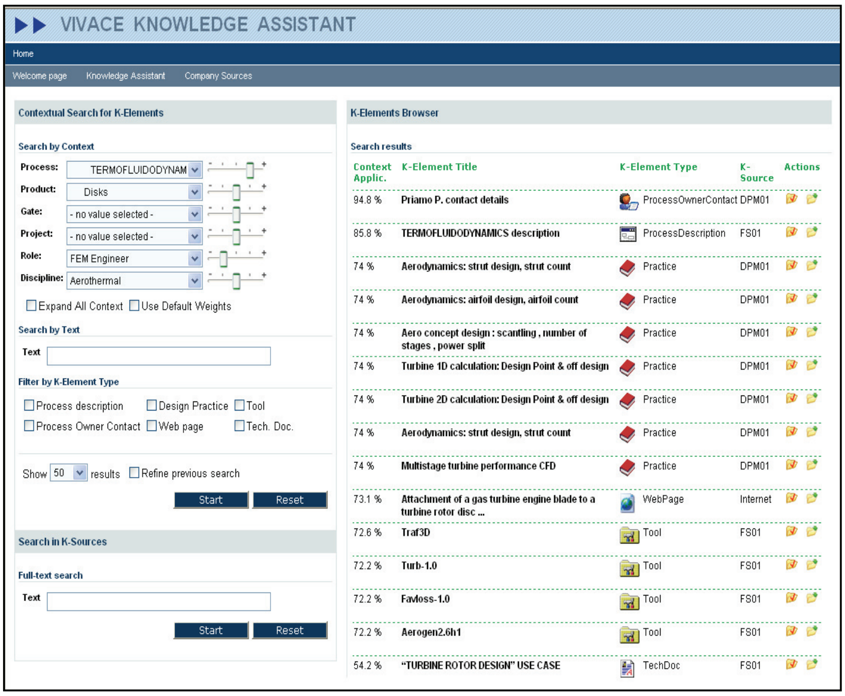
The approach that was taken led to the development of an innovative and comprehensive Knowledge Enabled Engineering solution composed of two different but complementary parts. The first supplies advanced software capabilities through a Context-based Search Platform, while the second provides general good practice techniques in the form of behavioural and methodological KEE Guidelines.

Validation

The results supplied by the KEE solutions have been tested through piloting within partner companies, with the final objective of validating the new concepts and functionalities through use in real company situations. Throughout each pilot, user feedback was collected by means of interviews and questionnaires. The results were documented in a pilot report, where they were measured against previously defined metrics consisting of quantitative and qualitative indicators. This allowed us to demonstrate the real benefits linked to the use of the proposed KEE Solutions in a To-Be design scenario as compared to the As-Is situation.

► CONTEXT BASED SEARCH PLATFORM

The objective of the technological approach was to allow knowledge to be correctly "filtered" before it is delivered to the engineer. The challenge was therefore to develop an intelligent knowledge assistant that automatically provides the engineer with the contextualised Knowledge Elements (elementary pieces of knowledge) that he or she really needs. Examples of K-Elements are: Practices, Norms, Tools, Drawings, Documents, Contacts, Deliverables, and Web Pages.



The result achieved is the Context-based Search Platform, a self-learning software system that enables the user to perform multi-source searches for all the Knowledge Elements applicable to his or her engineering context.

"Context" can be defined as any information that can be used to characterise the situation of an engineer. Within the Platform, the user's context is described by a set of six context dimensions: Gate, Product, Discipline, Process, Project and Role.

The Platform integrates typical search engine functionalities with advanced context-based methods and provides the following Generic Services:

- **Context Definition Service** – enables the engineer to pre-define the company's context model instance that will be used to represent the Engineering Context.
- **Context-based Knowledge Search Service** – enables searching based on user-context identification and the subsequent retrieval of applicable information
- **Knowledge Full-text Search Service** – enables searching for knowledge through a full-text search directly into the different knowledge sources used within a company

- **Knowledge Applicability Learning Service** – enables the platform to automatically learn, through user feedback capture, what knowledge is applicable to the engineering context
- **K-Element Metadata Store & Retrieve Services** – enables the K-Source to interface within the Extended Enterprise.

The software solution was designed following a "service-oriented architecture" and divided into three sub-systems developed using state-of-the-art technologies. Each sub-system (layer) is independent, and communication with other layers is guaranteed through internal web services. This architecture gives the platform great flexibility in terms of scalability and deployment scenarios, allowing centralised or distributed architectures within the Virtual Enterprise.

- **Portal Layer** – represents a possibility for the system's user interface and is implemented using an open portlet framework. It allows the user to set the context-based search criteria and filters.
- **Kernel Layer** – implemented using Case Based Reasoning (CBR) technology, it handles Knowledge Element applicability and the capture of knowledge use. This approach is similar to human reasoning when solving problems.
- **K-Source Interface Layer** – allows the system to interface with external Knowledge Sources such as databases or file systems and includes a commercial meta-search engine that provides integrated full-text searching.

Validation: Context-based Search Platform Pilot

Performed in an operational environment at the AVIO engineering facilities in Italy, this pilot involved a group of people with different roles and levels of company experience. The Context Based Search Platform was interfaced with different internal and external sources, including a document management system, a design practice manager, unstructured repositories, a collaborative environment and a web search engine.

In this specific pilot, besides user feedback, information was also obtained through the analysis of the software platform logs. The main indicators that were selected for pilot evaluation were user satisfaction, number of inconsistent results, K-Elements applicability, frequency of updating using feedback and learning time. The objectives of the pilot were to validate the context-based search approach along with the Search Platform itself.

The pilot proved the effectiveness of the context-based search method, considering the large number of new contextualised Knowledge Elements added to the Platform index, along with the continuous refinement of existing K-Element contexts. After successful validation in the engineering department, many of the advanced capabilities are being used in a multi-source search engine project that is currently in progress at Avio.

► Knowledge Enabled Engineering Guidelines

Knowledge Enabled Engineering is not as simple as purchasing a system or following a process: there are nuances and differences in organisations that must be taken into account. It is important to understand the nature of collaborative working and decision-making within a supply chain environment and why collaboration is often difficult to achieve by technology alone. To enable organisations to consider these aspects and embed good working practices, a set of KEE Guidelines have been produced. These also address the behavioural and methodological issues that arise from the necessary change in working practices as a result of implementing innovative knowledge solutions within organisations.

Knowledge Sharing Guideline

This Guideline enables the successful collaboration across the supply chain and dispersed collaborative teams by indicating good practice in terms of knowledge sharing, use of collaborative technologies and team working. It promotes a more transparent and proactive sharing culture and encourages early sharing of partially completed work within the Extended Enterprise.

Validation: Knowledge Sharing Pilot

Performed at BAE Systems, the main indicators selected for this pilot evaluation were user satisfaction, effectiveness, satisfaction with the task outcome, tool usage, satisfaction with individual and group participation, awareness, degree of connection among the teams and document sharing. The main objectives of the pilot were to understand effective knowledge sharing through the use of an off-the-shelf solution (MS Sharepoint) and to evaluate what techniques aid knowledge sharing, awareness and understanding.

The guidelines presented were derived from the lessons learned during real collaborative projects across BAE Systems and partner organisations. A team was observed implementing and subsequently using collaborative technologies, from which guidelines were distilled. Further, more generic guidelines were derived from case studies, past experience and dialogue with industry partners. Some of these have been actively adopted and promoted by the company as best practice.

Lessons Learnt Guideline

This Guideline facilitates the transfer of lessons learned across the extended enterprise by embedding the process of capturing success stories and lessons and maintaining knowledge assets for future use.

Validation: Lessons Learnt Process Pilot

The main indicators selected for pilot evaluation were user satisfaction, effectiveness, satisfaction with the task outcome, tool usage, degree of connection between the team and document sharing. The objectives were to validate how lessons learnt can help in business improvement, and to evaluate templates, the interaction with the supply chain and storage.

Airbus UK and BAE Systems have long implemented variants of a lessons learnt process, some of which are embedded into corporate processes. Airbus UK and a supply chain partner have taken this further by piloting the capture and sharing of lessons learnt between two different organisations on a collaborative design project, thereby demonstrating its applicability to the context of an extended enterprise.

Relationship Evaluation Tool Guideline

This Guideline gives users practical support in implementing a relationship management process when supporting knowledge exchange between supply chain teams. It enables the measurement of supply chain relationship performance using an adapted SCRIA (Supply Chain Relationships in Action) methodology and other support tools.

Validation: Relation Evaluation Tool Pilot

Performed at Airbus UK, the main indicators used in this pilot were user satisfaction, effectiveness, satisfaction with the group process, tool usage, satisfaction with individual and group participation, degree of connection between the teams and document sharing. The pilot objectives were to validate how the Relationship Evaluation Tool can help improve relationships across the supply chain and to evaluate where a team's current relationship stands, where they want to be and how to get there.

The guideline was used to evaluate and manage supply chain relationships in a 3-month business improvement project, covering eight workshops with two Airbus managers, two supply chain partner managers and further specialists from both operations and the supply chain.

Gated Maturity Process Guideline

This Guideline enables assessment and traceability of information quality in a gated decision-making process to assure confidence for decision makers in gate reviews. Continuously assessing maturity of decision documents and thus the information and knowledge in the process, the consortium avoids costly iterations that are usually decided upon and initiated at the gate review. This enables the consortium to reduce lead-time and ensures quality while at the same time reducing risk (since a decision is supported by evaluated maturity indexing).

Validation: Gated Maturity Process Pilot

This pilot involved business developers and marketing representatives in the civil, space and military fields within the Volvo Aero Corporation. The main indicators selected for pilot evaluation were effectiveness, satisfaction with the group process, tool usage, degree of connection between the teams, document sharing and overall process time decrease. The objectives were to understand the maturity criterion scale in a particular theme (i.e. cost calculation) of the 7 Day Proposal Process and to evaluate the feasibility of assessing the maturity of offer information and activities.

► INNOVATION PRODUCED

Convincing results in the Knowledge Enabled Engineering field led to the following innovation:

- An engineering context model to represent the user's context in aero industries
- Context similarity computation capabilities based on Case Based Reasoning
- The concept of knowledge applicability to the user's context

- Knowledge applicability learning capabilities based on users' feedback, enabling collective learning within the organisation
- Knowledge usage monitoring capabilities that could be used to assess knowledge assets
- Lessons Learnt Process enabling tacit to explicit knowledge conversion

► Next Steps

Though the work carried out produced interesting innovation in the field of Knowledge Enabled Engineering, there is still room for further investigation. One area that could be explored involves the possibility of offering advanced context identification capabilities, for instance through the automatic analysis of the user's working environment (open documents, applications in use, etc.). Secondly, in order to fully leverage this identified context, the area of adaptive applications could also be investigated: services should adapt to the context in which they are used and supply ad-hoc functionalities. Finally, all solutions must be analysed as a whole in order to allow the effective integration of context-based searching in end-user environments such as CAD, FEM, and PDM tools.

► Terminology

- **Applicability** – A function that indicates the relevance of a Knowledge Element within a specific user's working context
- **Case Based Reasoning** – (CBR) The process of solving new problems based on the solutions of similar past problems. Case-based reasoning is a prominent kind of analogy making.
- **Context** – Set of parameters (Product, Process, Gate, Project, Role, Discipline) that characterise a specific situation or event and that is used to assess K-Element applicability
- **K-Element** – Elementary piece of knowledge
- **K-Source** – K-Elements container, which may or may not have proprietary management functionalities
- **Pilot** – Application of a KEE Solution within a specific end-user environment / context

► Contacts and References

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Multi-disciplinary Design and Optimisation

Current state-of-the-art engines and aircraft are complex products. Their design combines various disciplines like aerodynamics, structures, aero-elasticity, safety, propulsion, noise, emissions, maintenance, etc. Each discipline can optimise the design with respect to its own relevant objectives. However, such single discipline optimisation cannot take into account the interactions between the disciplines involved e.g. optimising on weight might increase production costs or reduce maintenance intervals. Multi-disciplinary Design Optimisation (MDO) intends to arrive at an optimal design at aircraft or engine system level, based on a chosen set of measurable design criteria. As some (sub-)systems are complex and involve multiple interacting disciplines, similar MDO techniques can also be applied at (sub)system level.

The technical results accomplished by VIVACE focus on generic MDO technology validated through deployment in four use cases:

- Preliminary and unconventional design MDO (Prelude);
- Wing MDO;
- Whole engine MDO;
- Complex subsystems MDO (focusing on helicopters).

The work has resulted in the progress towards a generic framework, which has been applied in three use cases, as depicted below in Figure 53. The generic framework comprises concepts, methods and tools. The concepts include the integrated design model, which comprises a consistent set of all data required by every discipline involved in the specific MDO. Another generic concept is the use of a Pareto front to visually support the multi-disciplinary design team in assessing the trade-off between multiple conflicting objectives, a situation common in aeronautical MDO.

The generic methods and tools realised have been provided as generic services. Each of them will be described in the technical results section below, complemented with another deployable result.

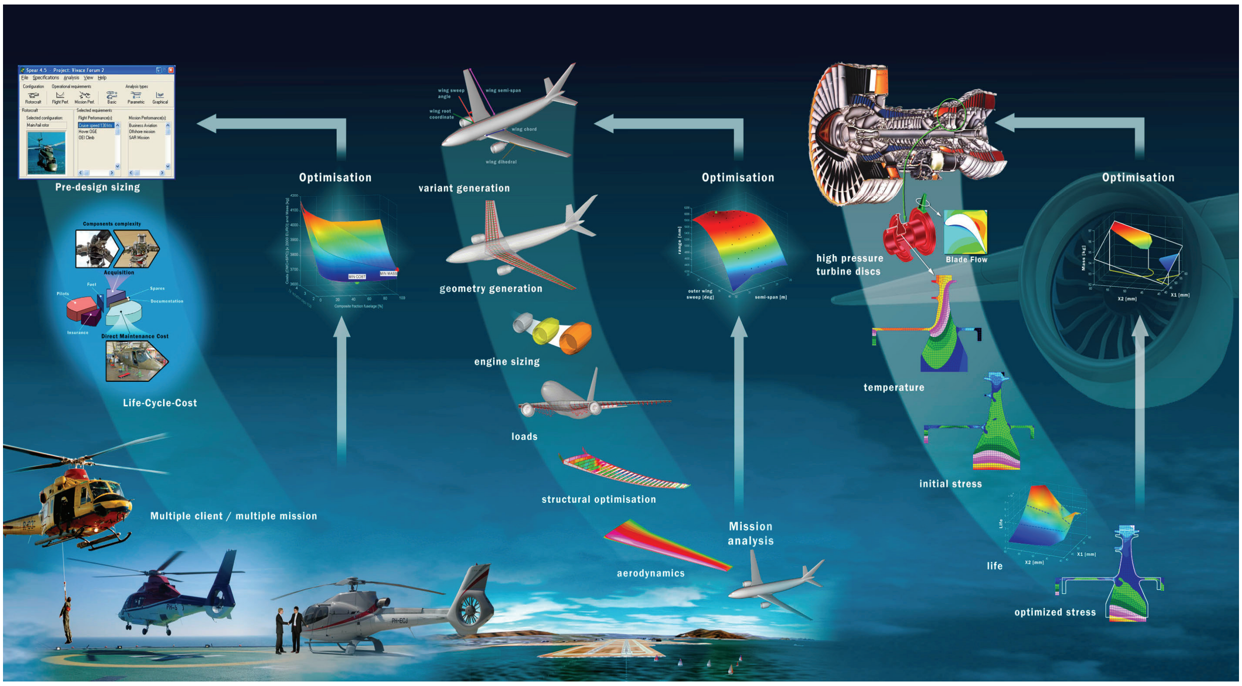

Figure 53: Generic MDO framework applied to three use cases comprising the life cycle phases from feasibility, conceptual towards detailed design in three aeronautic domains helicopters, airframe and aero-engine.

► TECHNICAL RESULTS

Below all generic services and the other deployable results are listed including the innovation achieved which will provide the benefits.

- Perform sensitivity analysis based on MPSD method

Perform a sensitivity analysis of the objective function for the Wing MDO system based on the MPSD method (Moment Propagation based on Sensitivity Derivatives). This service has been validated by the Prelude use case, with results provided in Figure 54.

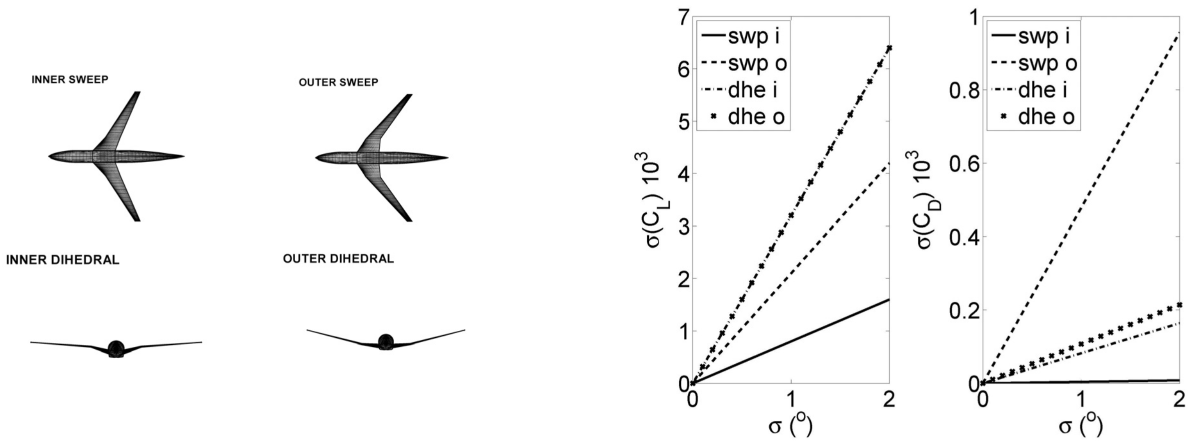

Figure 54: Sensitivity analysis service results

The innovation of this service is allowing the determination of sensitivity derivatives which may help to improve the efficiency of optimisers. For time-consuming analysis (typical in MDO) this reduces the number of design variants to be analysed.

- Response surface creation including data quality assessment

In case of time-consuming multi-disciplinary analysis, an approach is to sample the design space. Subsequently (a choice of) optimisers provided by the next generic service could use the response surface for the many intermediate design analysis needed by the algorithms. This service performs automated statistical analyses of MDO result data. Various fit functions are used, allowing the user to select to most appropriate one for the specific case. This service performs automated response surface creation and quality assessment. This service has been validated by the Engine**,** Helicopter and Wing use cases use case, with Figure 55 providing engine use case results.

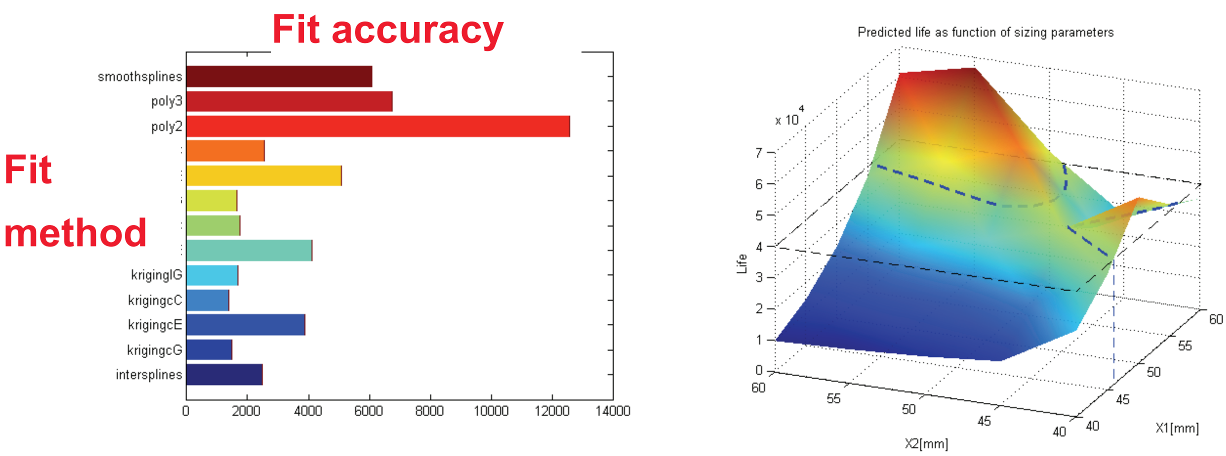

Figure 55: Accuracy of various fit functions to data (left) and resulting response surface (right) for best-fit function.

The innovation is to provide the MDO team with an efficient tool suite to select the best-fit method for the response surface for case at hand.

- Multi-objective optimisation environment

This service provides a choice of optimisation algorithms for an efficient search in high dimensional design domains i.e. design with multiple varying design parameters. The tool suite allows for optimisation of single or multiple non-linear design objectives and constraints. In case of multiple objectives, this result can be provided to support the MDO design team as a Pareto front. Some results from the helicopter use case are provided in Figure 56. This service has been validated by the Engine**,** Helicopter and Wing use cases.

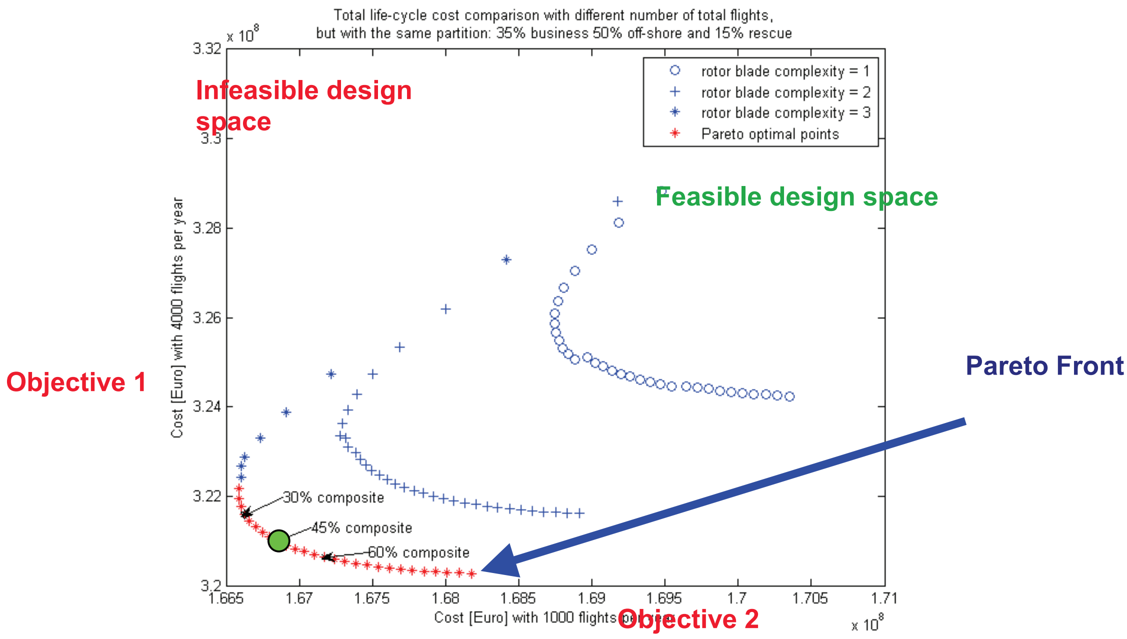

Figure 56: Pareto front for two objectives and several design variants based on varying percentage of composite in the fuselage and three types of rotor blade complexity.

The innovation is the increased ease of use of various optimisation algorithms including genetic algorithms to generate Pareto surfaces.

- Workflow manager device

Multi-level, monitoring and object oriented device for flexible and optimal computational plan within MDO studies (software application).

During the feasibility and conceptual MDO design phase, equations and functions (e.g. compiled code) are used to describe and model an aircraft. Two methodologies, the Design Structure Matrix (DSM) and the Incidence Matrix are used for the computational process modelling. The incidence matrix describes the relationships between variables and equations/models. The DSM has been used to express the dependency relationships between the models and also, after manipulation, to produce the solution process. The designer specifies the independent (known) variables first. Then the variable flow is modelled using the Incidence Matrix Method (IMM). It determines how data flows through the models, and also identifies any strongly connected components (SCC). The second step is to arrange all equations/models hierarchically in order to reduce the feedback loops in each of the identified SCCs. A Genetic Algorithm (GA)-based algorithm is applied for resolving the latter. Subsequently all SCC are assembled into a macro model which forms a global design structure matrix (DSM). The global DSM is further rearranged to obtain a lower triangular matrix that defines the final model execution sequence. Figure 57 provides a top-level overview of the service. The service has been validated by the Prelude use case.

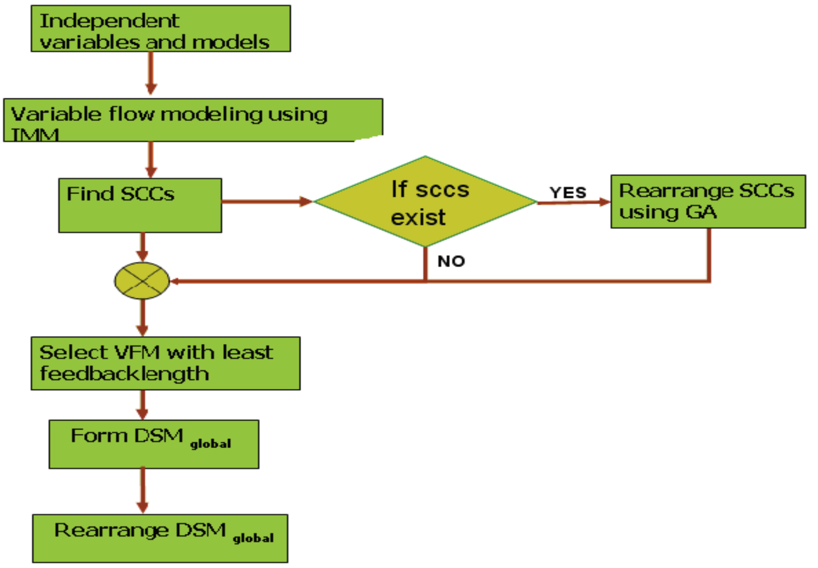

Figure 57: Top-level overview of the workflow manager device.

The innovation is the automatic determination of optimum order to execute many mutually dependent models (sets of equations), where this would be cumbersome using manual procedures.

- Computational Intelligence at Feasibility Design Stage: Calculation Engine

Multi-criteria optimisation and monitoring tool to identify sets of solutions of a MDO problem (mathematical methodology and software application). The tool is aimed at obtaining an evenly distributed set of Pareto points which will inform the decision maker of preferable design regions. The approach is based on performing a subdivision of the criterion (objective) space (CS) in a set of domains. The optimisation problem is then reformulated for each domain, for each of which a Pareto point is generated. To shrink the search domain and make its location in space more optimal, the Double Hyper-cone Boundary Intersection (DHCBI) method has been developed (based partly on the Physical Programming method) to generate simultaneously two opposite hyper cones for each sub-optimisation. This method is illustrated in Figure 58. The service has been validated by the Prelude use case.

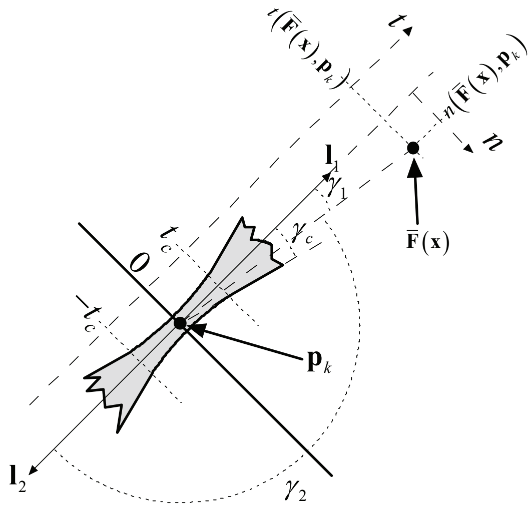

Figure 58: Illustration of calculation engine method.

The innovation is to improve the efficiency of Pareto surface determination.

- Automatic design information exchange

Automatic exchange of design descriptions and intermediate analysis results between tools integrated into a MDO tool chain. The MDO tool chain consists of Commercial of the Shelf and proprietary tools. The MDO tools are located across sites, organisations and countries. Figure 59 depicts a typical case of such multinational collaboration. This service has been validated in the Engine use case.

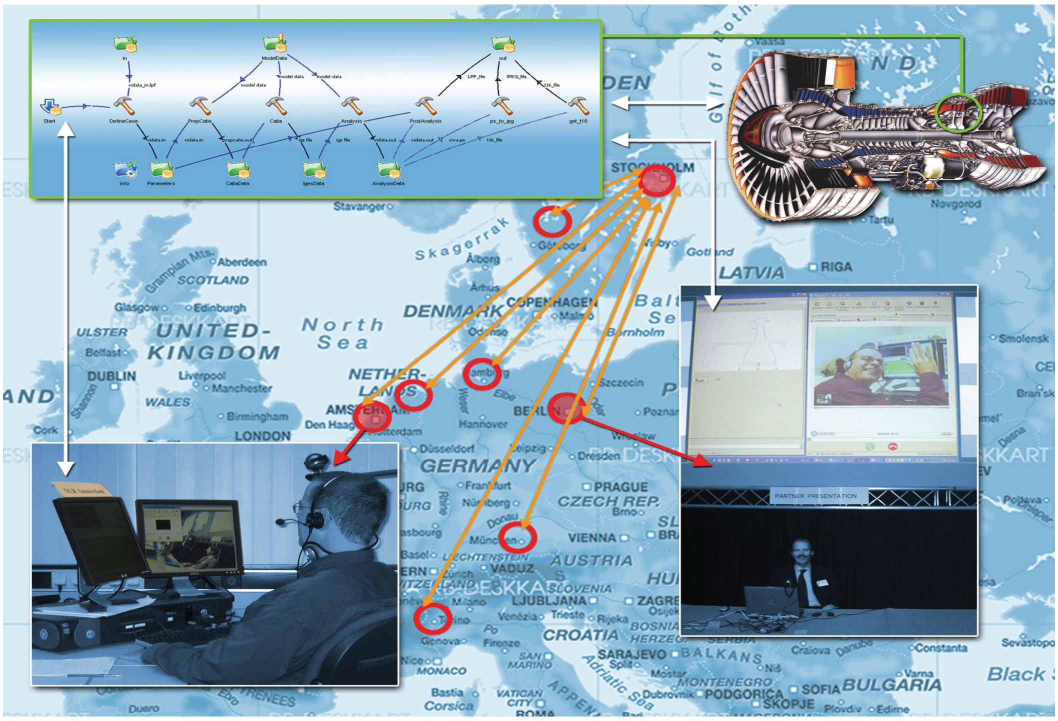

Figure 59: Illustration of automatic design information exchange in multi-national multi-organisational MDO setting.

The innovation is to improve the efficiency of the design processes for assessing the consequences of minor changes in (engine) component design amongst virtual enterprise partners.

- Providing remote web based access of a distributed tool chain

Based on the previous service allowing automated exchange design information and intermediate design results, this service provides web-based access to a tool chain, combing tools of various collaborating partners located across sites, organisations and countries. The implementation of this service is based on a federated collaboration model, i.e. each partner retains its own tool suite and only provides access to its tools for the other partners. This service has been validated in the Engine use case.

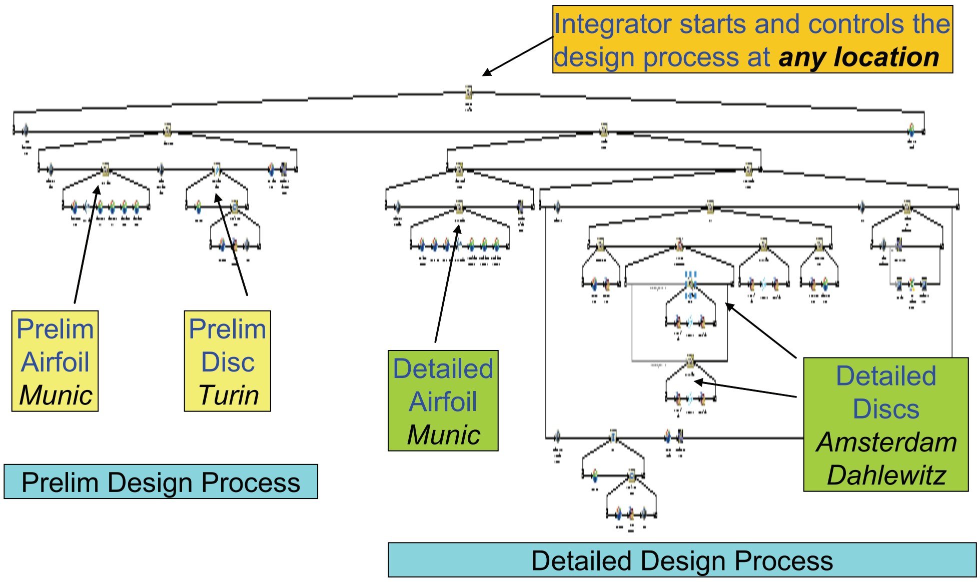

Figure 60: Illustration of automatic design information exchange in multi-national multi-organisational MDO setting.

The innovation is to enable design processes from one partner to use design processes of other partners at geographically dispersed sites of virtual or extended enterprise.

- Simulation toolbox framework

This deployable result provides a sizing loop for an aircraft wing using time simulation for load determination and an extended beam element tool for load analysis, coupled by a general sizing algorithm. The workflow is described in Figure 61. A first design of the wing (geometry, mass, stiffness) is introduced into the time simulation in which dynamic loads for the elastic aircraft resulting from one or more given manoeuvres are calculated. The load envelope found in the multi-body time simulation is exported to the structural analysis tool where the given design is checked for maximum stresses. According to the result the wing design is altered and the time simulation is re-run. If the design meets the requirements, the loop is finished and the results are exported, as illustrated in Figure 61. Test cases have been a 2.5-g-manoeuvre (see Figure 61) and a touchdown case.

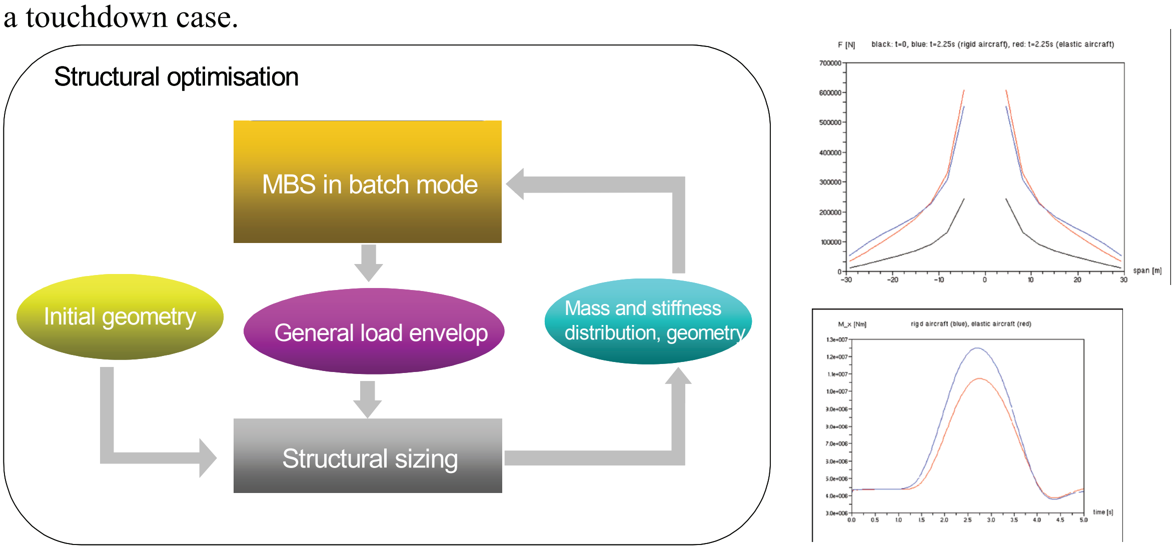

Figure 61: Structural optimisation tool box, top level overview (left) and Load distribution and root bending moment of rigid and elastic aircraft for 2.5-g-manoeuvre (right).

The innovation is that results show that the introduction of structural elasticity and dynamic loads from realistic manoeuvres even at an early design stage provides valuable insight into the system dynamics and is well worth the effort.

- TSCP-based secure collaboration

This result comes from the collaboration of VIVACE and the Transglobal Secure Collaboration Programme (TSCP). TSCP provides a technical, policy and governance framework for collaboration between independent organisations based in different jurisdictions The TSCP concepts have been deployed in an industrial use case of an aeronautical engine virtual enterprise. Figure 62 illustrates how the resulting access control has been realised. The innovation is to use TSCP standardised federated (hence scalable) identity management in an actual aeronautical virtual enterprise situation.

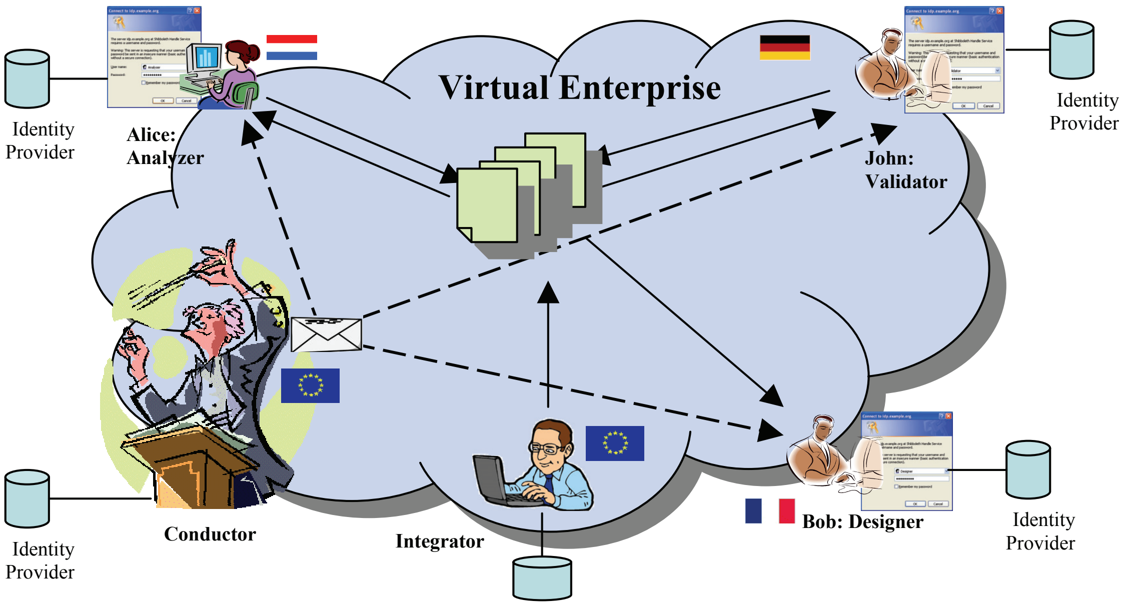

Figure 62: Secure TSCP-based access control for an aeronautical virtual enterprise.

Future work could address more automated support to the design team while investigating or defining the design space. Other ideas include integration of MDO with Product Life cycle Management for persistency of the results, integration with decide-to-decision services to justify decisions and integration with knowledge management for increased use of the knowledge obtained by the MDO. Progress towards a generic set-up of the integrated design model will reduce the cost of creating specific framework for each MDO application. The information should be intelligible for each discipline involved, the equivalent of what the Digital Mock-Up is for geometric information.

More information is provided in the public executive summary reports available for each deliverable, as published on the VIVACE public website. This MDO work has resulted in various public papers and presentations at scientific conferences, which are listed in the references section below.

► PUBLIC REFERENCES

This MDO work has resulted in 24 public papers and presentations at scientific conferences plus 6 presentations at the VIVACE Forum 1 and 6 presentations at VIVACE Forum 2 and 6 contributions to VIVACE Forum 3. All papers are available on the VIVACE public website.

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Design to Decision Objectives

Design to Decision Objectives (DtDO) addresses the specific needs of ensuring balanced design decisions during aircraft and aircraft engine development to reduce development costs and the time to market. This must be done in a well-defined process because development happens more and more in a multi-company and multi-culture environment. However, in this environment, the objectives become more complex and decisions must not only be balanced in terms of performance, cost and schedule but also take into account environmental, production work-share and comfort goals.

The product development process is very complicated and iterative due to the involvement of many different disciplines. Often, troubleshooting processes like weight or cost reduction cause high and unexpected non-recurring costs as well as partially unwanted secondary effects and a shortfall of engineering resources in the most important and time-critical development phases. A balanced "right first time" approach avoids lengthy time and cost consuming iteration loops right from the start.

Development costs and lead-time can be reduced by:

- Giving meaningful support at decision points in order to quickly find the best solution or way to proceed;
- Better handling of design changes during the development of complex products in a multi-disciplinary environment;
- Reduction of unnecessary iteration loops by balanced decisions;
- Documentation of important decisions in order to reach a better transparency of the decision process;
- Tracing the context of former decisions;
- Re-using experience in subsequent projects or programmes.

► ACHIEVEMENTS

Design to Decision Objectives provides a seamless approach and a set of methods and means to support complex multi-disciplinary design decision management for the extended enterprise business.

The means listed below exist as a standalone prototype and as generic services integrated with the overall VIVACE architecture of advanced capabilities. This enables the common application together with Engineering Data Management services (EDM), Multi-Disciplinary Optimisation (MDO) and/or Knowledge Enabled Engineer (KEE) capabilities. At this generic level it is possible to instantiate the services, whether in the (CHHE) or (DISI) environments, depending on the needs raised by the VIVACE use cases.

The developments include:

- **Providing a generic and seamless decision-making process (see Figure 63);**

The aim of providing a generic decision support process, the DtDO process, is to support people in setting up their individual decision processes within their business environment.

- A generic, seamless and integrated human decision-making process for engineering work and processes
- A guideline supporting the set-up and implementation of decision processes within a certain business context

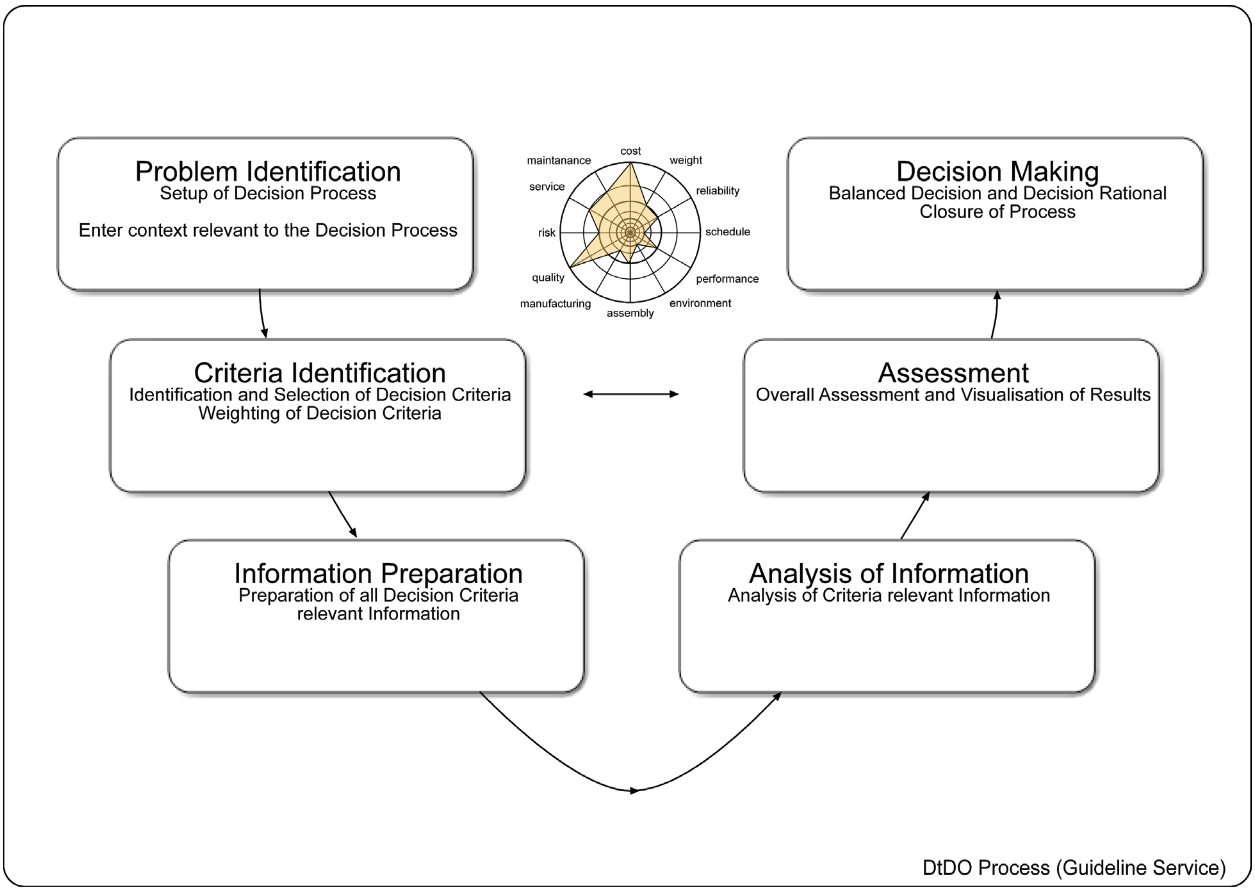


Figure 63: DtDO-Process

Providing dedicated analysis and assessment services;

DtDO analysis and assessment services particularly support the information analysis and information assessment steps of the decision process.

- **Change Impact Analysis Service (see Figure 64);**

The Change Impact Analysis service supports the decision maker by giving meaningful information about possible impacts of item changes on the overall system.

- The service enables the capturing and analysing of dependencies between project items such as components, requirements, tasks, etc.
- The service evaluates impacts of item changes on different disciplines in terms of lead-time, cost, performance, etc.

The Software Service provides functions for the:

- Preparation and visualisation of dependency models
- Analysis (change propagation, clustering, task sequencing, risk analysis)
- Results visualisation (graph/tree, DMU)
- Data import and export

Several validation use cases have been accomplished, e.g. for Architecture Behaviour Analysis Aircraft Cockpit, Requirements/Specification Traceability Pylon, and Multi-disciplinary Project Analysis Wing

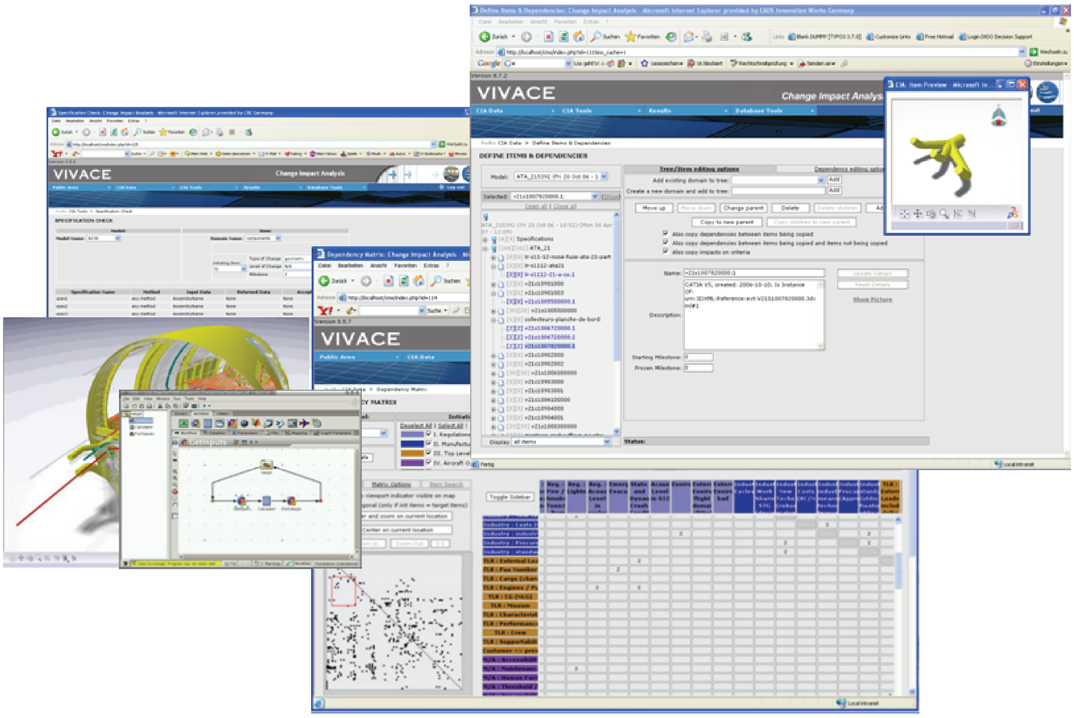


Figure 64: Change Impact Analysis Service

- **Handling Uncertainties Service (see Figure 65);**

The Handling Uncertainties Service addresses the need of capturing and calculating with uncertain information in the aircraft design process, especially in the pre-design phase.

- The service enables a seamless understanding and quantification of uncertainties in the aircraft pre-design process
- The service enables the handling and tracing of uncertainties right from the beginning
- The service provides a clear and easy to use graphical user interface

The Software Service provides functions for the:

- Capture of uncertainties
- Modelling
- Analysis
- Result preparation and evaluation

Several validation use cases have been accomplished, including a probabilistic parametrical Helicopter Weight Model

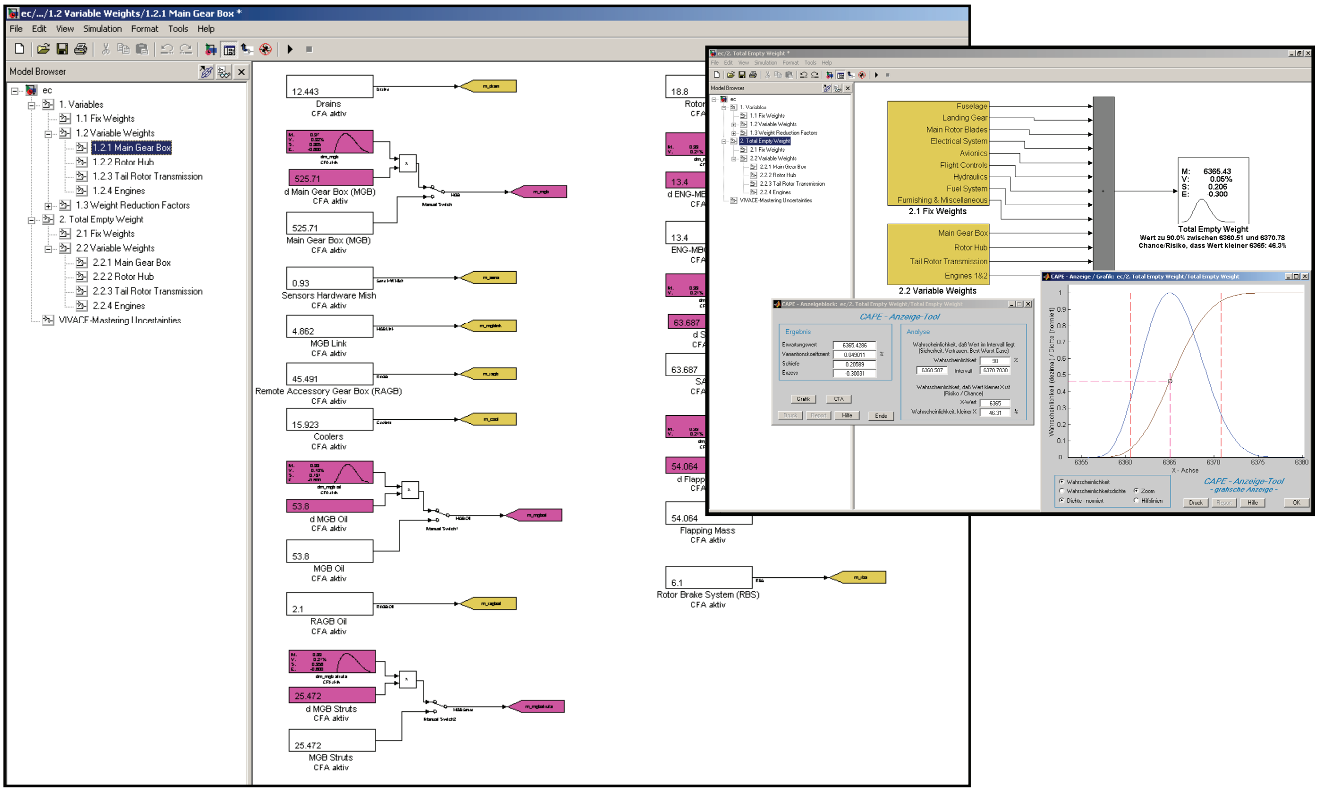


Figure 65: Handling Uncertainties Services

- **Life Cycle Cost Modelling Service;**

The Life Cycle Cost Modelling Service supports the preparation of LCC models for aircraft engines. The service includes:

- A common understanding and awareness of cost drivers during the overall life cycle of an engine programme
- Correlations and dependencies between the most significant life cycle cost parameters over the whole engine life cycle
- An Agreed Dependency Matrix to be used in the early phases of a new project to support the decision process

Providing a Decision Information Storage Service

The Decision Information Storage Service supports the capture of decision history and context in a "decision information object" which is part of the multi-disciplinary data model. The service ensures:

- The transparency of decisions and decision making process;
- The traceability of decisions

The Service provides Decision Object Information Architecture including:

- A data model view of decisions accessible through the PCM overall Information Model
- A data model that enables the capture and tracing of links between decision-relevant information and the operational context (Product, Process and Knowledge) through the PCM overall Information Model

For validation, a typical recurring decision scenario within a Request for Change process of an extended enterprise was taken as a use case.

Providing a Decision Support Framework and DtDO Framework Services (see Figure 66)

To support the use of the DtDO approach of running a seamless decision process and to take the greatest advantage of it, it is necessary to provide an environment that integrates the different decision support services and supports the user in exploitation.

With the DtDO Framework, we propose an initial implementation of an integrated environment. It incorporates the generic decision support process approach (DtDO Process) as a guideline service and supports the user in elaborating a customised decision process.

Further, the execution of the different process steps is supported by specific services to enter information (DtDO Framework Services). The Framework incorporates services for the analysis and assessment of decision information (DtDO Information Analysis and Assessment Services) and provides an environment to easily access, store and trace decisions their decision context (DtDO Information Preparation Services). These services include:

- An environment to guide the user through a formalised and traceable process;
- A customisable environment providing generic services to support each step of the decision-making process;
- An environment to integrate services that support the capture, analysis and evaluation of decision-relevant information;
- An environment to store, manage and trace decisions and their context.

The Software Demonstrator shows:

- An example graphical user interface
- A data base domain model
- The DtDO Framework Services
- The DtDO Analysis and Assessment Services (Link to CIA, AHP, Link to KESP, Link to PCM)

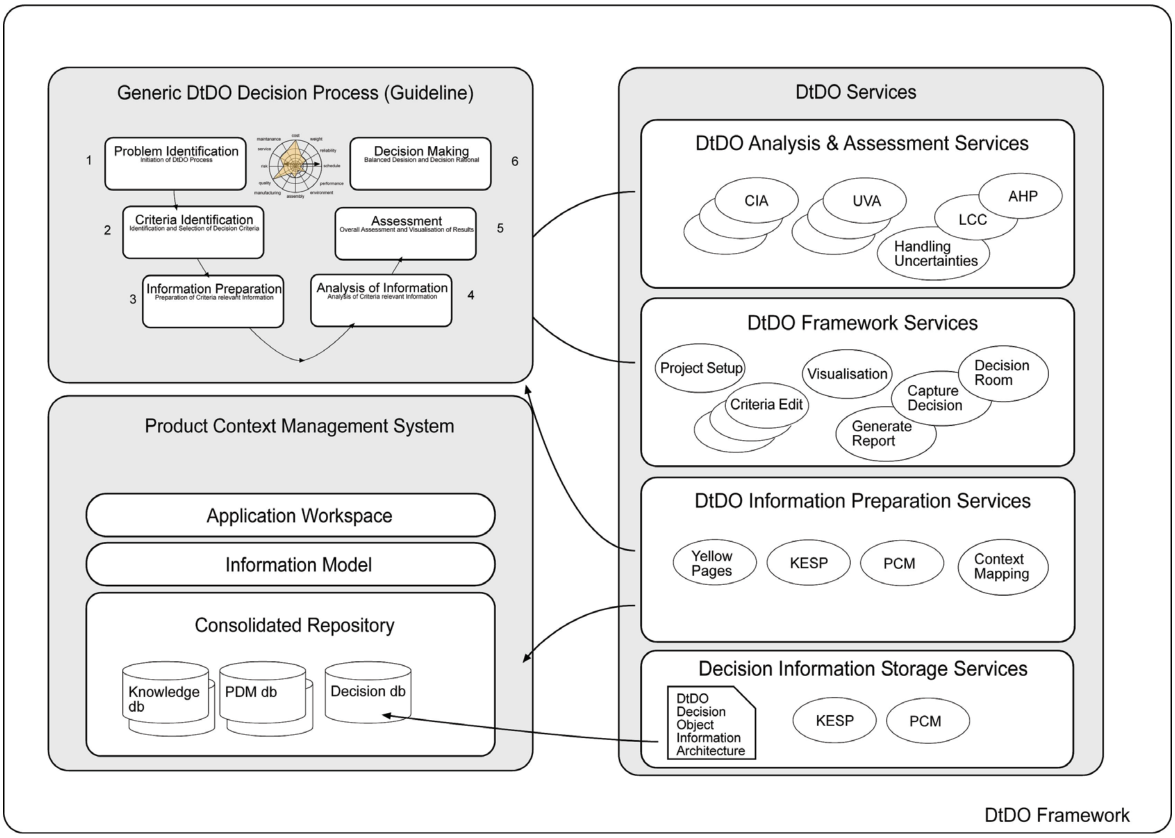


Figure 66: DtDO Framework

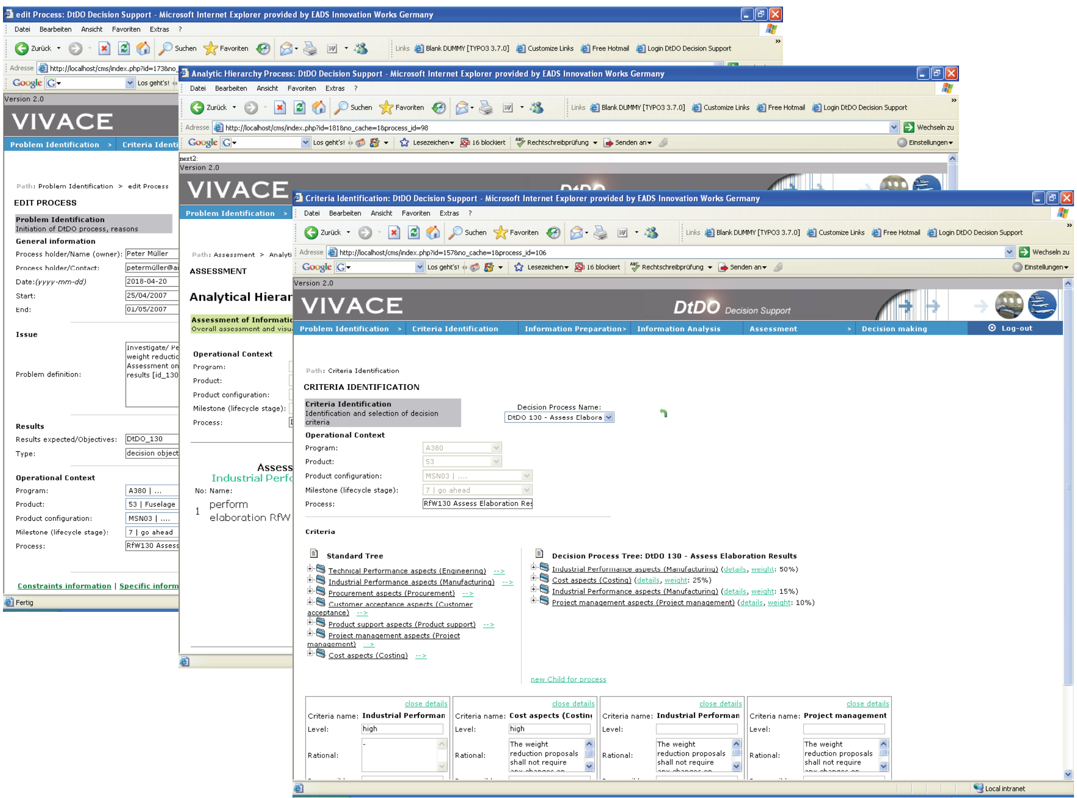


Figure 67: DtDO Framework Software Demonstrator

► PERSPECTIVE

With the DtDO Framework, a basic approach for an integrated decision support environment has been built. It allows the capture and tracing of decisions and supports the user in his decision process with dedicated analysis and assessment services. Independent of the use cases treated within VIVACE, the approach is applicable to a wide range of decision situations within a complex distributed product development process. A further development of this approach is intended, including the investigation of standardisation concepts for the decision object information architecture and the integration in an enhanced "Engineering Data Management System" of wider scope.

Furthermore, the deployment and validation of the DtDO Analysis and Assessment Services will continue within the partner companies.

Engineering Data Management

Within the context of the extended enterprise, collaborative design and data management processes from the early phases of a project have become crucial for faster, better product development. In this context, the heterogeneity and diversity of software, the data exchanges and their management between the different partners and through the different activities, have increased the need to create supporting "collaborative platforms". Their role is to enable the interoperability and associativity of the different data to be created and managed. When considering PDM systems, these aspects are characterised by the fact that data created, exchanged and integrated must have exactly the same semantic objects. As the number of attributes attached to the product also increases with the evolution of data management requirements, data exchanges and management between partners need more complete interfaces. As a consequence, there is also an increasing need to provide control on data processed through these systems.

Data management systems and "collaborative interfaces" (such as middleware) are facing two major issues:

- The capability to enable the semantic parsing of data; this issue relies on the capability to define and extract the collaborative and semantic objects so that they can be exploited by partners and activities that need them;
- The ability to contextualise data; this issue relies on the capability to determine the context in which data has to be processed.

In a context of a proposed collection of middleware and collaborative hubs for data solutions, we propose the definition of a non-invasive architecture (meaning that the "in house" configuration of the partners is not impacted) based on the modelling of context and data models of tools. The Engineering Data Management (EDM) approach is motivated by the fact that data are still not well integrated and interoperable within the different partners' systems.

► Major Innovative Concepts Addressed

The EDM objective is to provide Advanced Capabilities.

The major goals targeted by EDM framework activities are to provide:

- **A non-invasive framework**: Enterprises already have an "in-house" environment running with their processes. The objective of such a framework is not to replace existing environments, but to provide interoperable "middleware" that should be able to integrate existing tools and methods. The EDM framework proposes an add-on based solution to complete user environment features provided by Product Lifecycle Management (PLM) and Simulation Lifecycle Management (SLM), COTS, legacy tools, customised portals, etc. This approach leads to the definition of accurate domain models from the different environments involved, to enable a scalable interoperable environment at multi-partner, enterprise or discipline levels.
- **A standards-based ontology**: This is the major issue in setting up an interoperable environment. Heterogeneity of semantics and formats means that business concepts described in domain models are not exploited in the same way from one environment to another. The EDM framework targets the enabling of domain interoperability by using a

semantic reference based on standards. XML and STEP provide mechanisms to describe and exchange the information involved in collaborative activities.

- **Services to provide information in context**: Within the interoperable environment, in order to efficiently use any kind of data exchanged or shared, the associated context must be known at each moment. The context identifies the data and provides a way to localise all the information associated with this data: Product, Process and Resources. The EDM framework proposes an Information Model that provides the context of usage and domain models to determine data involved in an activity.

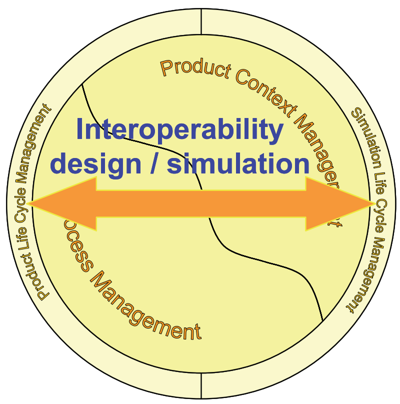
In order to reach those goals EDM proposes innovative concepts that will enable:

- Management in context of heterogeneous data (Design and Simulation data);
- Persistence of accurate information for exchange and sharing;
- Management of business process between partners, domains and disciplines.

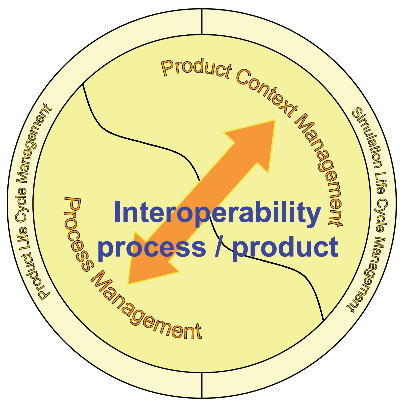
TECHNOLOGICAL OVERVIEW

Four levels of interoperability needs were identified during the analysis phase of the different VIVACE use cases:

- The first obvious need of interoperability in VIVACE concerns the ***link between the Design discipline*** on one hand and ***Simulation and Test disciplines*** on the other hand. The EDM framework tries to create a bridge between heterogeneous Design and Simulation (and Tests) environments. In fact, Engineering Data Management creates a bridge between Product Life Cycle Management and Simulation Life Cycle Management.
- The second need of interoperability is between ***product and process***. This interoperability is strongly linked to the ***context*** of information. The EDM framework manages a product context above any information published by a user. For any piece of information, this context provides a link between the product, process and resources associated with this information.



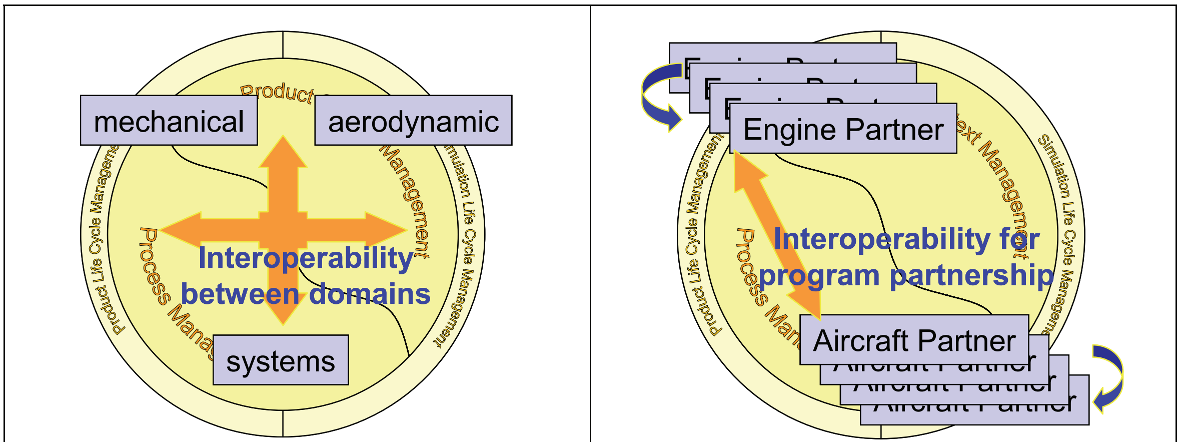
Interoperability at Disciplines level



Interoperability at context level

- The third need of interoperability concerns ***multi-domain links*** (mechanical, aerodynamic, thermal, system, etc.). The EDM framework provides the interoperable environment to publish the necessary sub-set of Domain Models for multi-domain activities. It proposes within this interoperable environment the mechanism to fully or partially consolidate the different Domain Models in a Standard Consolidated Repository.

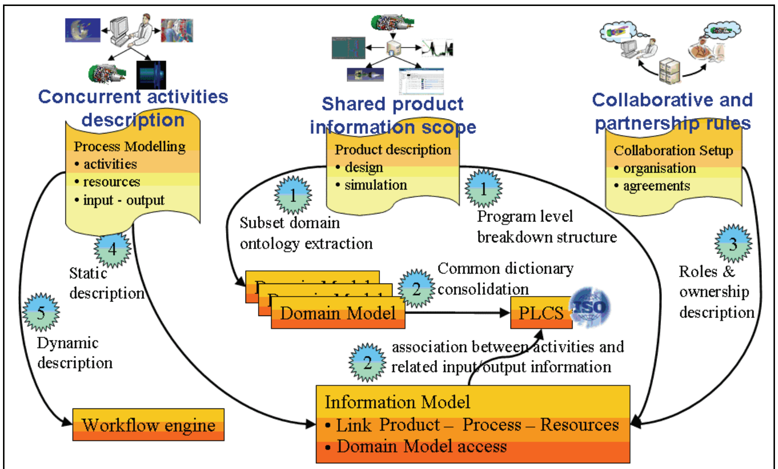
- The fourth need of interoperability concerns ***multi-partner links*** in the context of the Extended Enterprise. Typically in the VIVACE project, the multi-partner interoperability need is common to all the use cases concerned with collaboration around the Engine programme and all the use cases concerned with collaboration around Engine-Aircraft integration. The EDM framework must provide interoperability mechanisms that facilitate exchange between heterogeneous environments in terms of size and solutions and must also provide solutions compatible with confidentiality issues between partners.



Interoperability at domain level *Interoperability at business level*

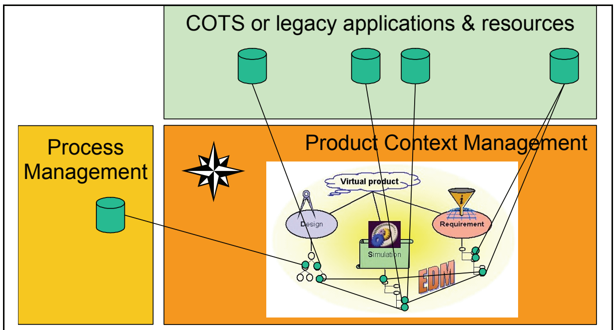
In order to ensure the different levels of interoperability, the EDM framework defines a set of concepts to enable the **Product Context Management**:

- The **Domain Model** describes the subset of a business user's ontology. From an EDM point of view, ontology is the exhaustive conceptual map that describes a domain; a conceptual map is a schema of the concepts and their inter-links used by a discipline to perform its activity. The domains users (mechanical, aerodynamic, system, etc.) from the different engineering disciplines (design, simulation, test, etc.) describe a subset of their model. In doing this, they define their view of the product and delimit the information they want to share for collaborative engineering activities.



Product Context Management set-up

- The **Consolidated Repository** (or Consolidated Model) enables the persistency and consolidation (merging) of different Domain Models through the STEP application protocol 239 (PLCS). Product Life Cycle Support (PLCS) is an ISO STEP standard (ISO 10303-239) that enables the creation and time management of an Assured set of Product and Support Information (APSI) which can be used to specify and control required support activities throughout a complex product's life.



integration of user environment

- The **Information Model** is a navigation service for the multi-disciplinary domain models. It provides a mechanism to define an engineering context of work. This engineering context links the product, process, resources and applicable knowledge to perform an activity within a project.
- **Product Context Management** is a management service of product data in the context of a business activity. Product Context Management uses the Information Model to ensure the consistency and traceability of the engineering context and to localise information associated with the engineering context and localised in the Domain Models. Product Context Management uses Domain Models to produce the business views expected by business users. Additionally, Product Context Management offers services to integrate legacy "in house" environments into the new approach.
- The **Process Management** and Control is provided by a process management component (workflow engine).

▶ IMPLEMENTED ARCHITECTURE

The EDM services are deployed in a logical architecture composed of three layers:

- A layer dedicated to **Process Management,**
- The **operational and collaboration** layer that contains the activity tools (COTS, legacy tools and portals),
- A layer implementing **Product Context Management**.

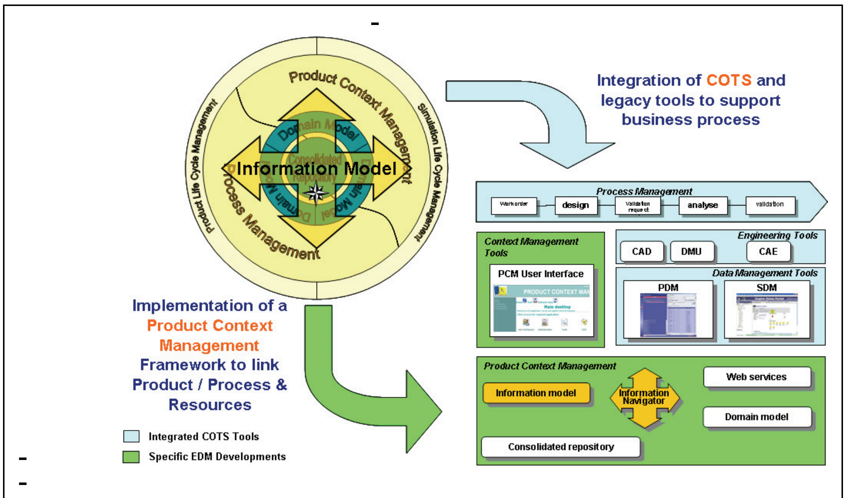
The Process Management layer provides the dynamic aspect of the Process in terms of workflow implementation, tools communication and interoperability.

The operational tools are, for the Design activities, PLM systems coupled with CAD and DMU applications and for Simulation and Test activities, SLM systems coupled with CAE facilities. As the EDM framework targets integration and not substitution of these tools, Product Context Management supplies connectors to communicate with the PLM and SLM environments. The connectors are based on the web services and enable the exchange of information that needs to be consolidated.

The activities shared by different partners, different domains, or different disciplines are performed in collaboration tools. The collaboration facilities are demonstrated in the EDM framework with the dedicated user interface (PCM UI) and with connections between Product Context Management and applicable portals.

The Product Context Management layer constitutes the infrastructure of the EDM framework architecture. It is composed of:

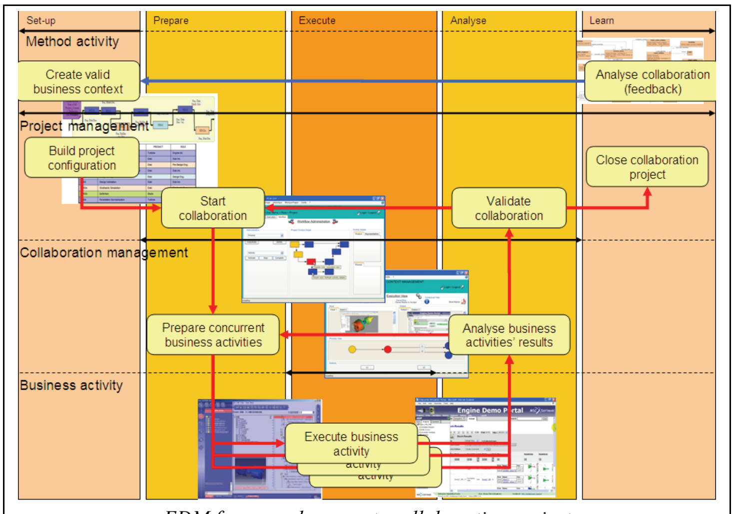
- A Communication component, offering web services to build connectors with operational and collaborative tools;
- An Information Model component (associated with the Information Navigator service), that offers the contextualisation of information (product, process, resource, applicable knowledge, decision, etc.);
- A Domain Model component, that provides a frame for each domain or discipline so as to publish and share the information needed for collaborative tasks;
- A Consolidated Repository that provides a frame for multi-domain consolidation of information in a common semantic: PLCS.



EDM logical architecture

Based on its logical architecture, EDM provides the capability to prepare, run and analyse a collaborative project from an information (data logistics) perspective:

- **Prepare:** select/adapt the Information Model for this collaboration
- **Run:** move the starting information from the Virtual Product repository to the collaboration environment, provide the mechanisms to access/enrich product information via the Information Model (depending on context), move the result data from the collaboration environment to the Virtual product repository
- **Analyse:** update the Information Model for future collaborations if needed



EDM framework supports collaborative project

From industrial constraints, EDM Framework developments were driven to:

- Use a standard so as to develop the interoperability between the different data;
- Provide a non-invasive structure so as not to interfere with the partners' "in-house configuration";

- Develop a layer of collaborative services;
- Create models to manage relevant data for interoperability.

Such constraints have encouraged us to turn to STEP (STandard for the Exchange of Product model data – ISO 10303). The use of such a standard to answer the different issues is motivated by the fact that some models have already been implemented in industry and that the application range is sufficient enough for the aeronautic industry. The use of the PLCS (Product Life Cycle Support – AP239) and application protocols such as AP 209 and related PART 42 and 104 provide enough semantic referential to develop, for example, a model between design and simulation. With the same objective, the language of EXPRESS is consistent enough so as to provide a real architecture implementation.

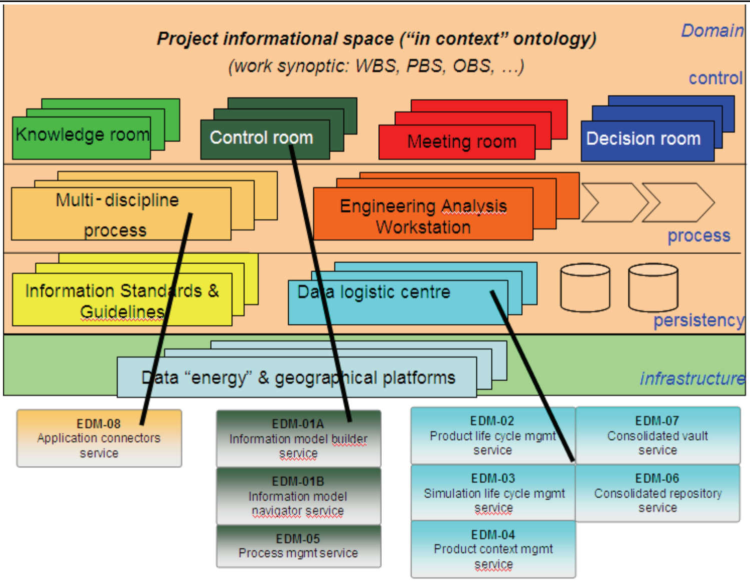
► TECHNICAL ACHIEVEMENTS

The EDM framework concepts described above are implemented in a set of services available in the VIVACE Toolbox.

Together with the other VIVACE advanced capabilities, EDM services contribute to building a informational project space. EDM services relate to three VIVACE toolbox layers: the Control, Process and Persistency layers.

- In the Control layer, the "Control Room" component contains the following EDM services:
  - **Information Model Builder** Service that enables the user to interactively describe a Domain Model within the EDM Information Model
  - **Information Model Navigator** Service that enables the user to interactively implement a Domain Model within the EDM Information Model
  - **Process Management** Service that enables to the management of processes that support the Design, Simulation, & Tests activities
- In the Process layer, the "Multi-discipline process" component contains the following EDM service:
  - **Application Connectors** Service that enables the creation of direct communication links with COTS applications
- In the Persistency layer, the "Data logistic centre" component contains the following EDM services:
  - **Product Life Cycle Management** Service that enables managing, under configuration control, all the necessary Product Data that are handled by the EDM Framework
  - **Simulation Life Cycle Management** Service that enables managing, under configuration control, all the necessary Simulation & Test data that are handled by the EDM Framework
  - **Product Context Management** Service that enables keeping track of the context in which data were created
  - **Consolidated Repository** Service that enables the creation of a common repository for all data handled within the EDM Framework
  - **Consolidated Vault** Service that enables storing the files within the EDM Framework

All of these EDM services are assessed at TRL 4 (i.e., Technology component and/or basic sub-system development in a "research" environment).



EDM service contribution to VIVACE toolbox

► Benefits of EDM

The EDM Framework is an efficient way to reduce lead-time and costs in a collaborative product development environment. It helps to:

- Deliver the right ***information***, at the right ***time***, to the right ***actor***, in the right ***format***, within the right ***activity or process***,
- Easily update, exchange data and ***design contexts***,
- Reduce iterations and early design phases duration.

► What's Next

The EDM concepts can be extended to support a Virtual Overall Aircraft model architecture and develop the corresponding capabilities to enable work in a collaborative and virtual "plateau".

For this purpose, robust integration has to be managed in order to fully take advantage of the intelligent model and the product-process management capabilities. In that way, an industrial "product context management" implementation would enable the simulation and design of an optimised, cost-effective and high quality final product.

DISI – Distributed Information System Infrastructure

► The Distributed Information System Infrastructure (DISI)

DISI is an infrastructure composed of software and hardware that proposes different Information System environments. DISI enables users to test and validate capabilities and scenarios within the Extended or Virtual Enterprise.

In the VIVACE framework, DISI has contributed to rating test and validation results at TRL4 or TRL5.

TRL (Technology Readiness Level)	**Definition**
9	Actual technology system proven through successful (reliable & maintained) operation in service.
8	Actual technology system completed and qualified through test and demonstration
7	Technology prototype implementation and validation in an "operational" environment
6	Technology component and/or sub-system integration and prototype demonstration in a "verification" environment.
5	**Technology component and/or basic sub-system demonstration in "verification" environment**
4	**Technology component and/or basic sub-system development in "research" environment**
3	Analytical & experimental critical function and/or proof-of-concept
2	Technology concept and/or application formulated
1	Basic principles observed and reported

DISI contribution (TRL 4 and 5)

► DISI Architecture

1) Hardware

DISI is composed of two satellites linked by a VPN and accessible by all VIVACE partners through the internet. These satellites are equipped with a standard configuration called **DISI In A B**ox (DIAB) which provides the required capabilities to run the VIVACE scenarios. These configurations are composed of a Database server, a web server, Unix servers and offer a global backup service.

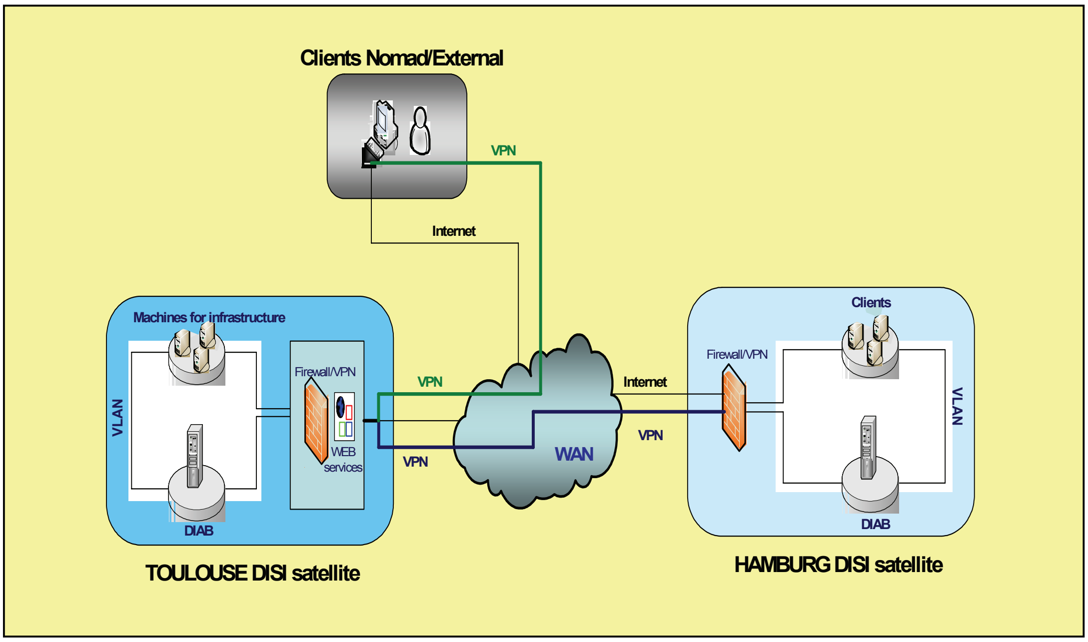


Figure 68: DISI hardware

2) VIVACE TOOLBOX

The VIVACE Toolbox is the base service on which all applications used to perform the scenarios rely.

The VIVACE Toolbox is composed of two types of tools:

- **Core tools** being permanently installed on the DIAB, which act as the common base of all applications.
- **Optional tools** to be installed on the DIAB regarding the scenario demonstration needs.

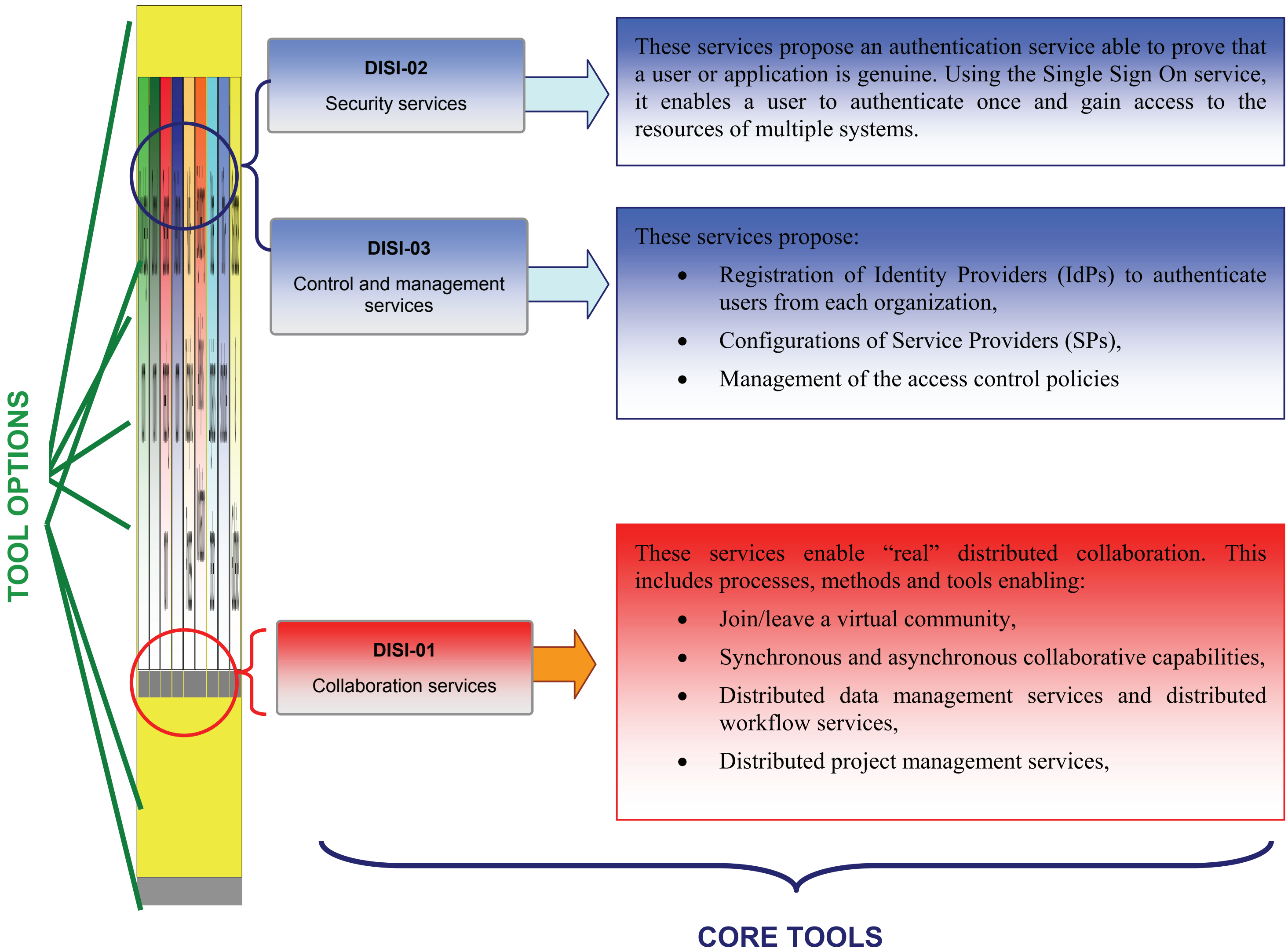


Figure 69: DISI services

3) Capabilities

To provide a secure environment, DISI simulates DMZ-like configurations interconnected via VPN.

Access control includes SSO and Federated Identity authentication.

To make full use of the available hardware and the VIVACE Toolbox, the VMware technology has been selected to create, on each DIAB, the following Virtual Machines:

- **EPM :** VMware EPM/WEB (PDTF Portal)

  OS: Windows 2000 pro

  Applications: Apache/JDK + Tomcat + Express Data Manager + PDTF

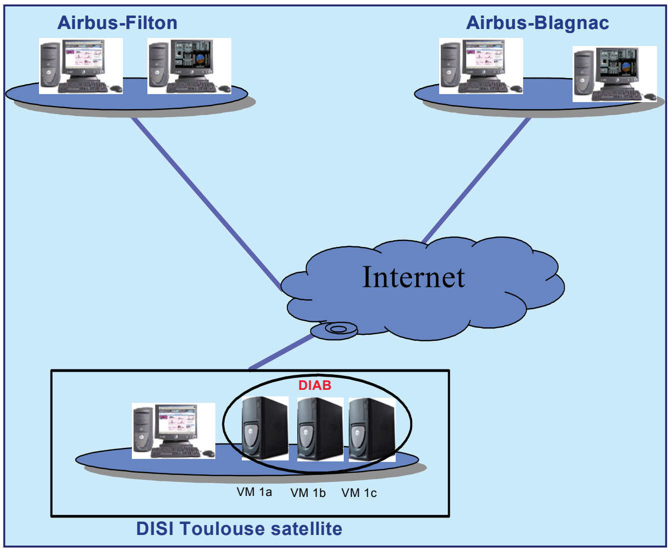
- **MSC :** VMware MSC/WEB (Simulation Portal)
  OS: Windows 2000 pro
  Applications: Oracle DB8i + Apache/JDK+ Tomcat + MSC software
- **SELKIS :** VMware Enovia AS
  OS: Windows 2003 Standard Edition
  Applications: Oracle DB Server 9.2.0.10 + Java Runtime 1.3.3.08 + Enovia LCA + Catia P3 solutions V5R16 + Websphere AS Express 5.1.1 + MQ 5.3 + MQ Workflow 3.4 or 3.5
- **SOKARIS :** VMware Catia Standalone – Vault Cache
  OS: Windows XP pro
  Applications: LUM client + Oracle DB Server 9.2.0.10 + Java Runtime 1.3.3.08 + Enovia LCA + Catia P3 solutions V5R16

DISI MODE OF OPERATION

DISI architecture offers different possibilities to simplify the integration of services so as to take full advantage of the available hardware and services.

1) DISI SATELLITE AS A PARTNER OF THE SCENARIO

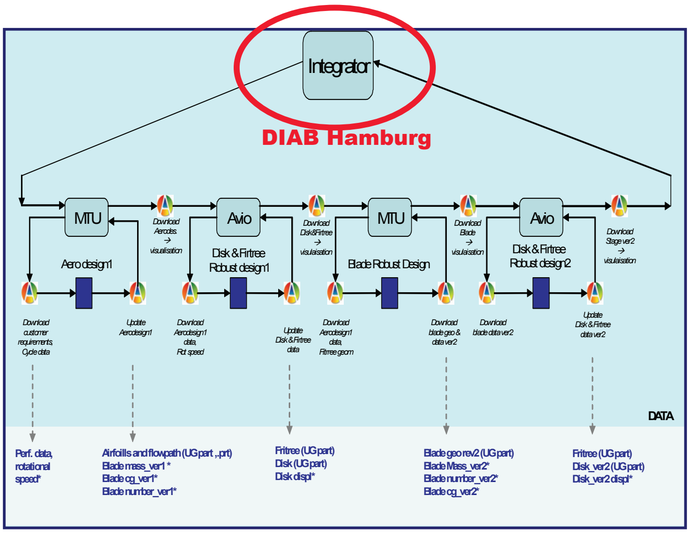
In theses examples DISI has contributed to each scenario as a partner. Specific Virtual Machines have been set up to simulate the Information System requested to play the expected role.



To contribute to this scenario, DISI Toulouse satellite has set up the following virtual machine:

- **VM 1a**: Dynawork 5.2, Exceed 7.1.1
- **VM 1b**:Tomcat 5.15, J2SE, Eclipse, Pugin Tomcat Sysdeo, MySQL, MySQL connector, MySQL-adm, MySQL Query Browser, TRUTS Library
- **VM 1c** : Typo 3

Figure 70: DISI Toulouse satellite contribution



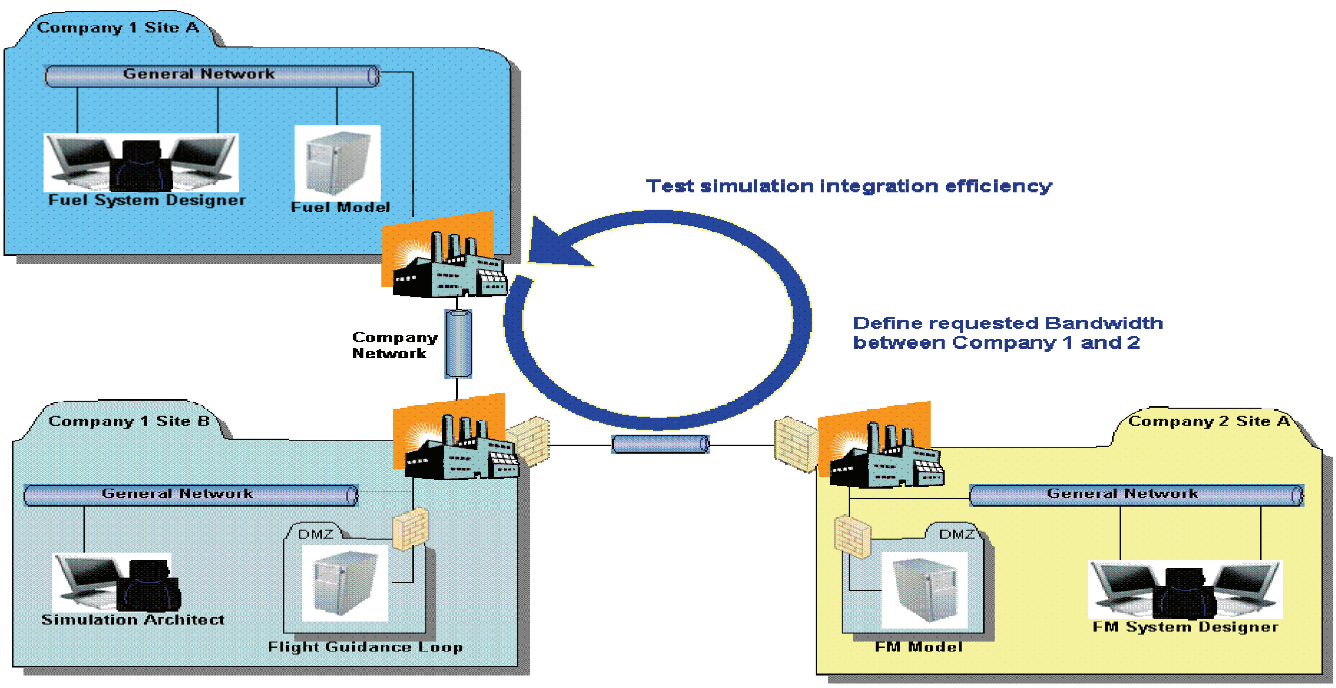
To contribute to this scenario, DISI Hamburg satellite has set up the following virtual machine:

- **VM 1d**: Webspere 6.0.2, DB2 8.2, FIPER 2.5, ISIGHT-FD 2.5
- **VM 1e**: Apache 2 Webserver, Tomcat 5.15, Oracle 9i, PDM Link, Project Link, Aphelion LDAP Directory, Java Enterprise Edition 5.0 SDK

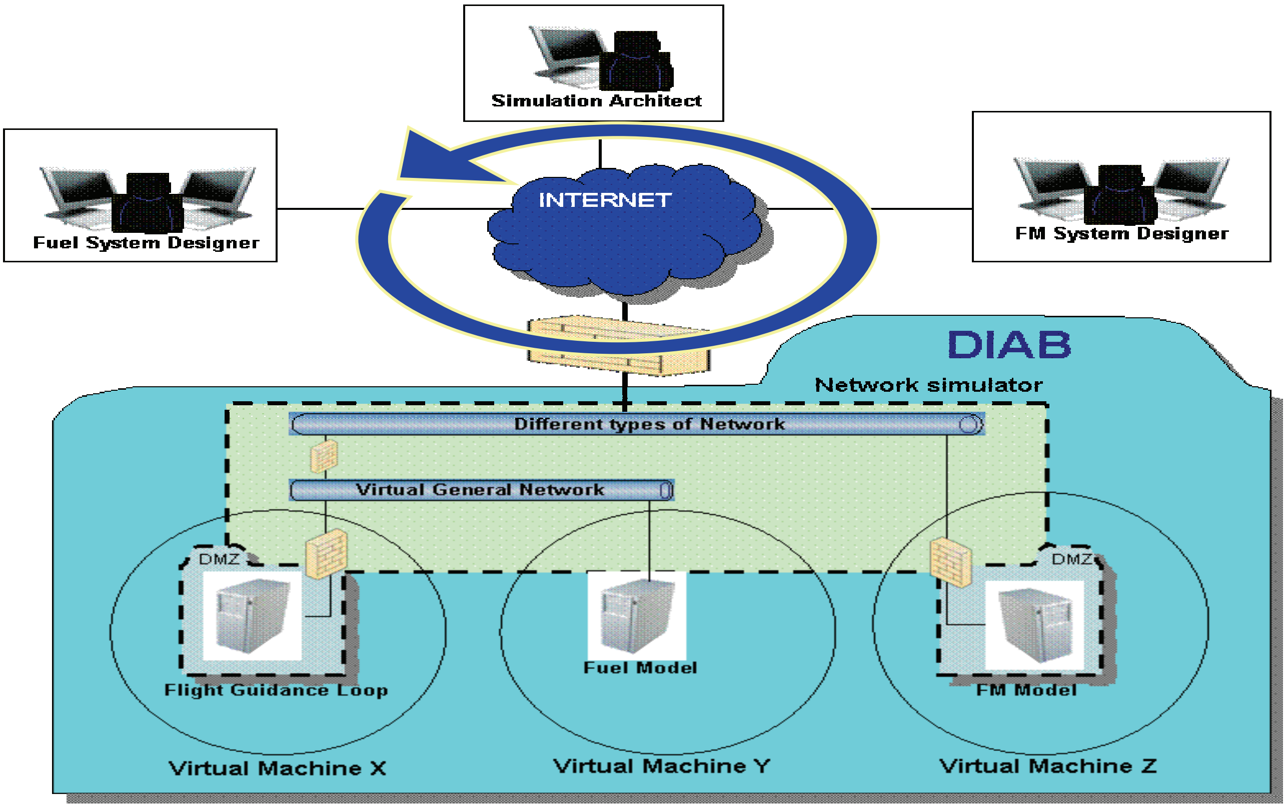
Figure 71: DISI Hamburg satellite contribution

2) DISI AS A SIMULATOR OF THE EXTENDED OR VIRTUAL ENTREPRISE

The flexible DISI architecture permits extended/virtual enterprises to be simulated, an example of which is illustrated in the diagram hereafter.



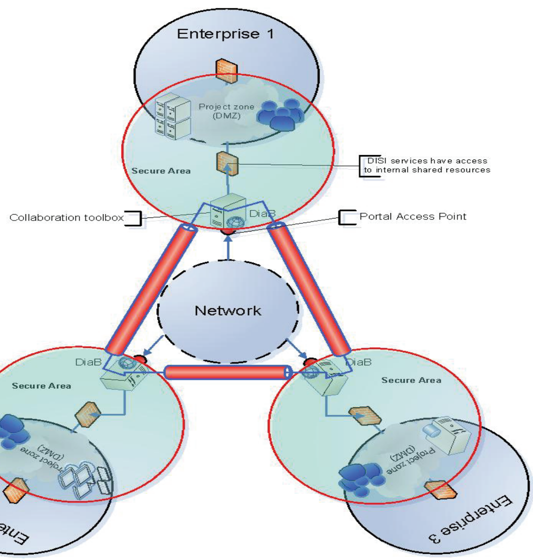
The DIAB can be remotely accessed by involved partners to run their scenario according to their access rights (see following diagram).



3) DISI AS SECURE VIRTUAL COLLABORATIVE WORKSPACES

Two types of secure virtual collaborative workspaces are proposed by DISI:

- A distributed architecture

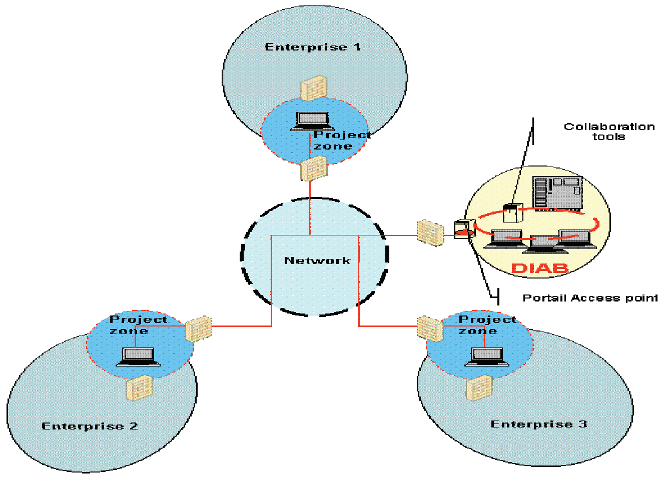


In this configuration, each enterprise hosts a DIAB.

Thanks to the DIAB, each enterprise can set up its own **Secure Collaborative Workspace** composed of the resources (hardware and applications) it accepts to share with the other enterprises for performing the scenario.

As each DIAB is connected to the others, a **Secure Virtual Collaborative Workspace** is then created, gathering all resources given for the scenario. Each enterprise can join the workspace through its own access point.

➢ A centralised architecture



With the centralised mode, a third-party manages the DIAB which gathers all shared resources (hardware and applications) in a **Secure Collaborative Workspace.**

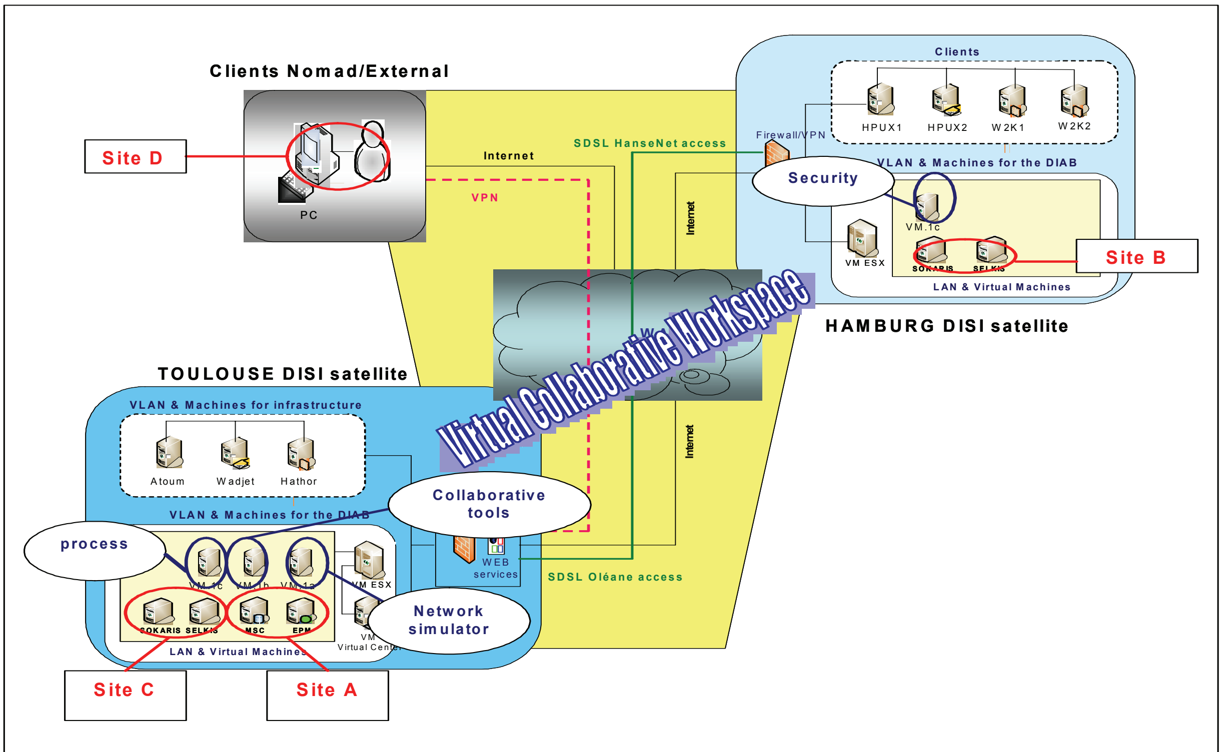
Each authorized enterprise, by connecting to this single point of service, can access the workspace.

Each organisation shares a project zone. The project zones are interconnected within a secure collaborative space thanks to a Portal Access Point enabling users to access their personalised services.

DISI Functional Architecture

The DISI architecture simulates a secure network (in yellow in the diagram below) that interconnects satellites (in blue) that manage VMware servers.

The DISI toolbox provides a set of core tools for each satellite that enable access control, services enumeration, collaborative applications, backup and so on.



Collaboration Hub for Heterogeneous Enterprises

► Business Drivers

Staying competitive in today's business implies being able to operate and collaborate efficiently in a Virtual Enterprise[1]. This requires being able to cope with the following challenges:

- The heterogeneous business network environment;
- Accessibility of the common collaboration context;
- Enabling a flexible network of partners;
- Requirements on traceability and storability;
- Ownership of data, methods and knowledge;
- Security, trust and legal aspects.

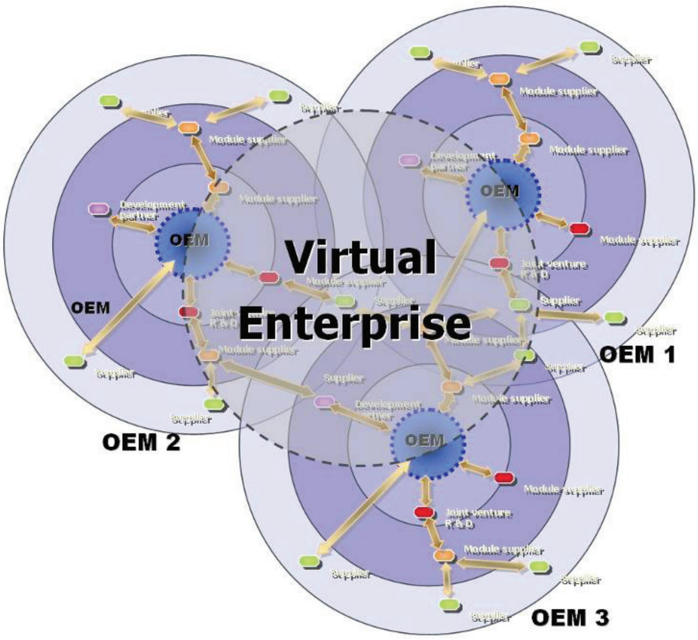


Figure 72: The Virtual Enterprise context

► Business requirements

By use and scale-up of emerging ICT[2] methods and tools a collaboration environment to support the Virtual Enterprise can be developed. The requirements on the targeted collaborative solution include:

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[1] The Virtual Enterprise is the network of partners and suppliers that work together to reach common goals. In this environment there is no single partner that decides the infrastructure, tool set or processes to be used.

[2] Information and Communication Technology

- A common agile set-up of partner roles, product information, work processes and reference data for the collaboration project;
- A neutral partnership collaboration platform with respect to technical (vendor and system), internal and external aspects;
- Partner to partner isolation via intermediate services communicating using neutral data structures;
- Accessibility via commodity technology such as web browsers to collaboration environment assets.

► THE VEC-HUB CONCEPT

The concept of the developed Virtual Enterprise Collaboration Hub, VEC-Hub, meets the business requirements and forms a foundation for the operational environment of the Virtual Enterprise. This gives everyone, within the heterogeneous IT environment of the partners, the ability to securely and traceably find, consolidate and publish information and collaborate in a common context.

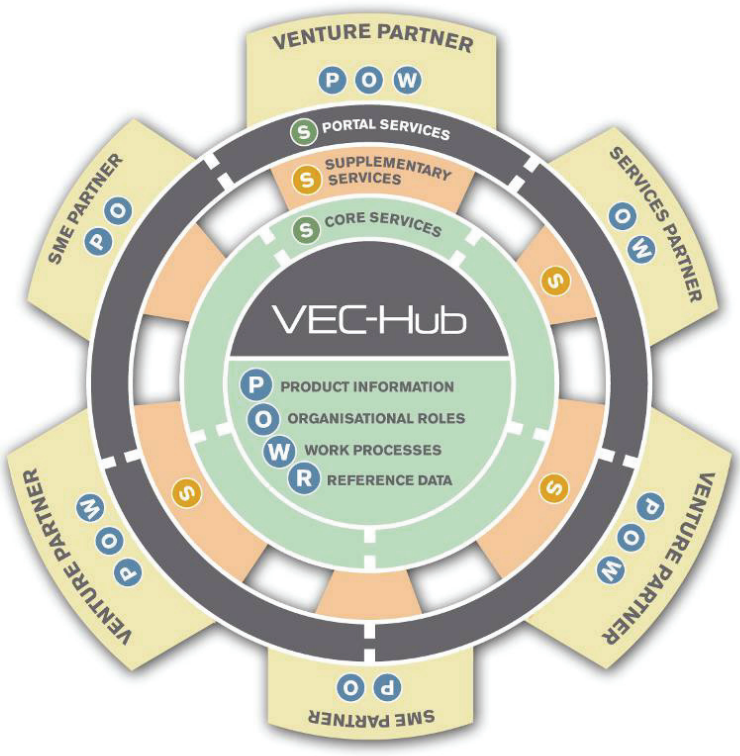


Figure 73: The VEC-Hub conceptual layout

The outer dashed circle of the conceptual layout represents the portal front for the VEC-Hub area of interest providing (S)ervices for access, management and security. Outside of this area each collaboration peer maintains their private view on internal (P)roduct information, (O)rganisational roles and (W)ork processes.

Three main kinds of collaboration peers have been identified:

- Venture Partners that are capable of providing internal (P), (O) and (W) assets for collaboration

- Small to Medium sized Enterprise Partners, SME Partners, with mainly commodity tools available for collaboration
- Services Partners that provide supplementary (S)ervices supporting the collaborative workflows

The inner dashed circle in the green area represent the core (S)ervices of the VEC-Hub that orchestrate the processes and information storage

The interior green area represents the common view on (P), (O), (W) and (R)eference data for the collaborative work

The area between the dashed circle and the interior green area is called the shared area of the VEC-Hub. Here directly integrated partners can communicate internal (P), (W), (O) information via supplementary (S)ervices in control by the VEC-Hub core services.

The VEC-Hub Concept specialises the Service Oriented Architecture (SOA) paradigm by defining:

- **VEC-Hub Portal services** – providing security management to ensure control over data and services, and service management to provide visibility of and interaction with services.
- **VEC-Hub Core services** – providing services described and accessed in a standardised way enabling partners to share product data, organisational data, reference data and processes, including workflows.
- **Supplementary services** – providing the means to enable access to services outside of the core set yet complying with the interface requirements for the VEC-Hub. An example is supplementary services that enable partners to open an on-line interface into their own internally running processes and data storage while maintaining control of the access and usage of those services.
- **Standardised interfaces** – providing one standardised Application Programming Interface for applications to access the VEC-Hub services and one Graphical User Interface to enable access the VEC-Hub services using commodity tools like a web-browser.

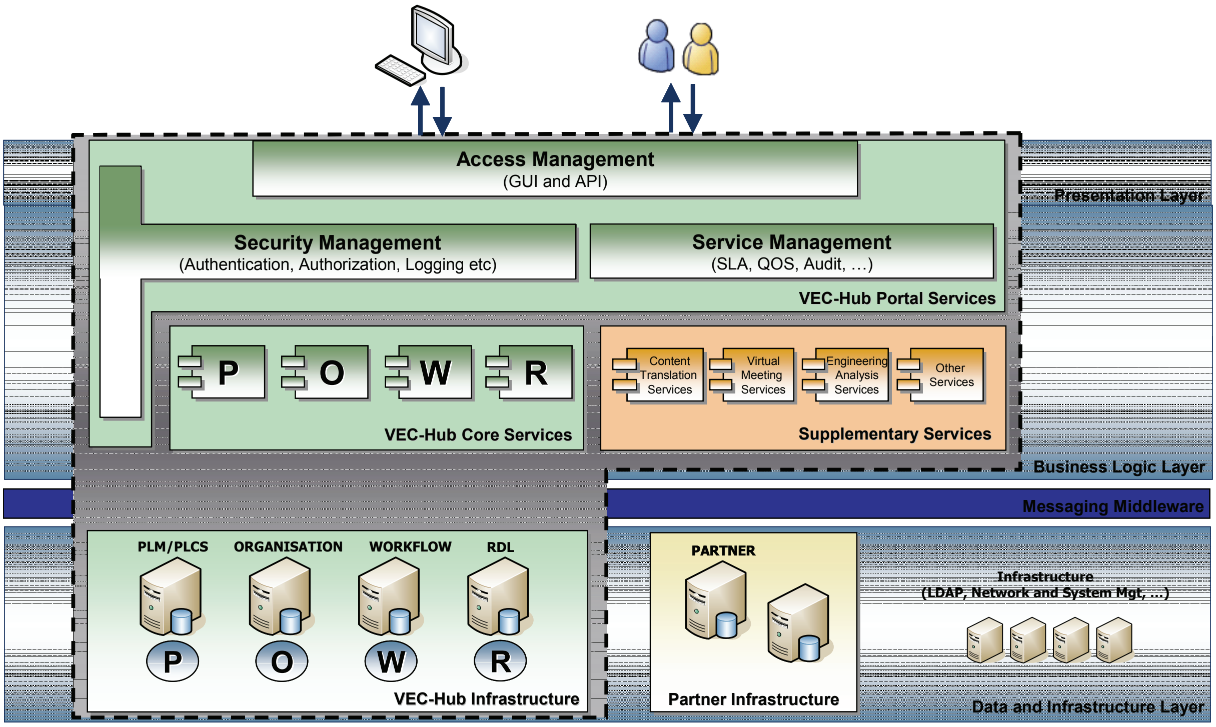


Figure 74: The VEC-Hub logical architecture.

During the lifecycle of a product, the VEC-Hub set of services will change due to the specific requirements in each phase.

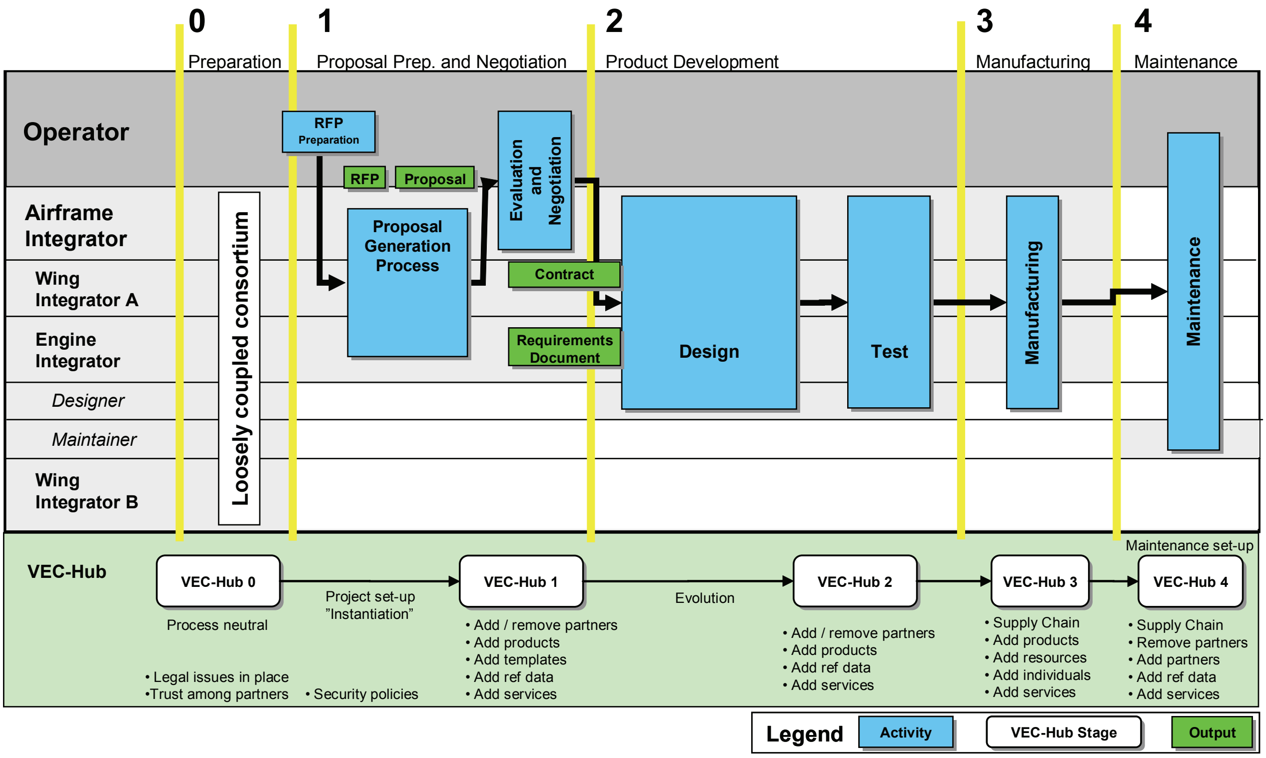


Figure 75: The VEC-Hub Concept supports the Virtual Enterprise during the full lifecycle of a business/product.

In the *Preparation phase* the VEC-Hub enables management of the large number of potential partners in a loosely coupled consortium. It sets the focus on the selection of suitable partners and the legal issues regarding the collaboration e.g. IPRs (Intellectual Property Rights).

In the *Proposal preparation and negotiation phase* the VEC-Hub provides services for managing products, processes, organisations and reference data.

In the *Product development phase* the VEC-Hub facilitates the interaction with supplementary services, i.e. partner supplied services plus suitable external services that the specific collaboration will need.

In the *Manufacturing and maintenance phase* the VEC-Hub provides management of the product data, organisation, processes and reference data used by the supply chain and product support organisations.

► SUPPORTED BUSINESS NEEDS

- To ensure long term review and re-use of information content independently of the software used for its creation or updating;
- To massively reduce the burden of maintaining an up-to-date product structure model as the design acquires more detail and fidelity, allowing:
  - Responsiveness to component re-design;
  - Significant reduction in design time;
  - Operational across a collaborative network.
- To increase the pace of initiation activities and securing the quality of the outcome of a new product or maintenance plan proposal:
  - Tailor-made solutions;
  - Rapid scope and partner changes.
- To enable the collaboration between different companies during the design phase:
  - Easily access and share system requirements and design constraints;
  - Quickly share component design;
  - Improve effectiveness of the design verification loop, facilitating analysis techniques and / or multidisciplinary optimisations.
- Complying with partner security rules.

► RE-USABLE CAPABILITIES

A total of 30 re-usable capabilities have been developed:

<u>The VEC-Hub Concept Specification</u>

Describes how an orchestrated set of services organised in a VEC-Hub provide shared information to a set of partners working together.

<u>The VEC-Hub Usage Guideline</u>

Guiding the user on how to use the VEC-Hub in the various phases of a collaborative project:

from the preparation, through the proposal preparation and negotiation, to the actual design, manufacturing and maintenance.

The VEC-Hub Implementation Guideline

Describes the implementation process from first software installation to a point where the end users start using the system. In addition maintenance work and administrative processes that happen during the lifetime of a VEC-Hub are described.

VEC-Hub Portal Services

Provide the VEC-Hub interface to the users, an integration platform for partner systems and the service request broker. These services include access management, security management and service management.

VEC-Hub Core Services

Provides the means to manage and share information common to the Virtual Enterprise including product data, organisational data, reference data and processes. These services are the ones that characterise the VEC-Hub since they define the common view on the product and its structure, the organisations/persons with their roles and access rights, the basic processes like “change request” and in addition the classification of product data. This includes the group of standard services published in OASIS to manage PLCS/PLM information based on ISO10303-239.

Content Translation Services

Enables seamless integration of heterogeneous information sources with common semantics.

Virtual Meeting Services

Manages the initiation, running and reporting of virtual meetings.

Engineering Analysis Services

Supports sharing and management of simulation models and results, together with execution of federated models.

International Information Standards

ISO 10303-233 – System Engineering and Design

ISO 10303-26 – Binary representation of EXPRESS-driven data

► Next Steps

Planned public training sessions on:

- VIVACE Forum 3, Toulouse, France, 17 th - 19th of October 2007;
- VEC-Hub Concept training, 26th of November 2007;
- VEC-Hub Usage training, 27th of November 2007;
- VEC-Hub Implementation training, 28th - 29th of November 2007.

► References

VIVACE origin: http://ec.europa.eu/research/transport/projects/article_3628_en.html

VIVACE public results: www.vivaceproject.com

ISO and Industrial Data: www.tc184-sc4.org

OASIS: PLCS - www.oasis-open.org/committees/plcs

OASIS: SOA RM - www.oasis-open.org/committees/download.php/19679/soa-rm-cs.pdf
W3C Web Services: www.w3.org/2002/ws

Third Tier Suppliers in VIVACE

► Introduction and Objectives

A dedicated VIVACE work package considers the interests of smaller suppliers within the supply chain. It is specifically aimed at 3rd tier suppliers, or smaller organisations who are typically design or production companies that support sub-systems; or component suppliers for aeronautical activities in Europe and who operate within the aeronautical supply chain.

Its objectives are to:

- Assess the requirements of 3rd tier suppliers in relation to the technologies and methods that relate to collaborative and virtual engineering;
- Provide these requirements to the other work packages for application in the research undertaken and method definition under the VIVACE programme;
- Assess the methods developed by VIVACE and the implications that 3rd tier suppliers will have to consider in the future supply chain;.
- Define security policy and methods which support the Virtual environment that smaller companies will need to apply;
- Support the dissemination programme with the results from the activities defined here.

► Specific subjects being addressed

The main issues being considered relate to the way in which smaller organisations will be required to operate in the future, with the emphasis being on the operation within supply chains using the collaborative engineering methods being generated by VIVACE.

In reality, the results from this work have bearings on other levels of the supply chain and considerations also for the procurement process.

An understanding of the profiles and characteristics of third tier suppliers has been collected and an understanding of the issues associated with the working environment that VIVACE will eventually define has been determined – hence allowing an impact assessment to be done. This information is being made available to organisations around Europe, as well the critical research and development functions of the VIVACE programme. This assessment has considered:

- Strategy;
- Project Management;
- Process;
- Enabling ICT arrangements;
- Information and knowledge management;
- Team working;
- Control and improvement activities within the supply chain.

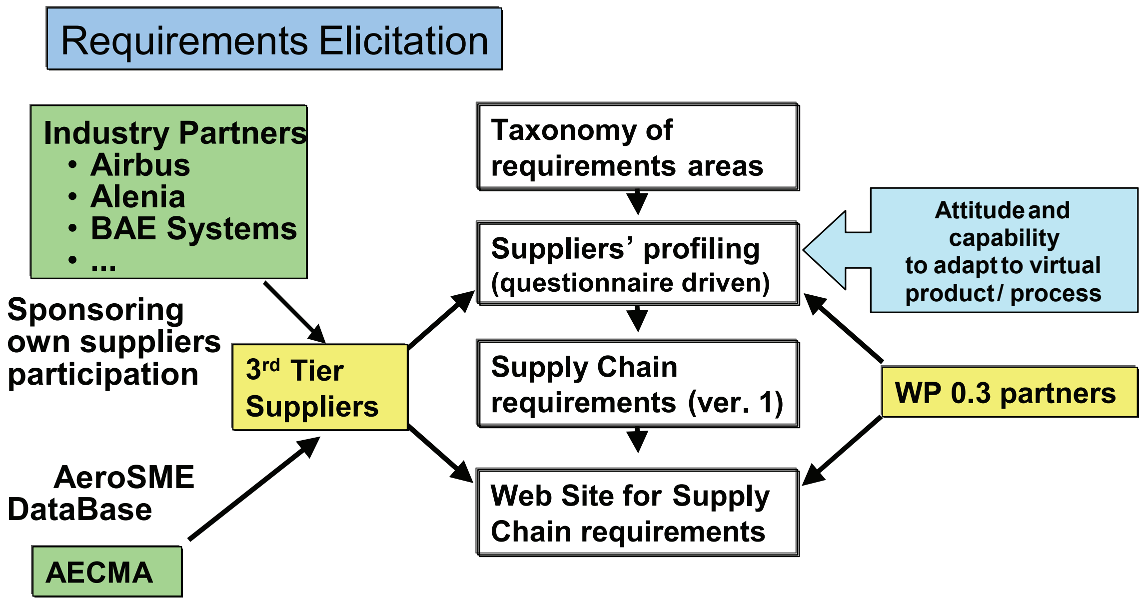
To achieve the objective across this range of topics, interactions with smaller organisations, supply chains and organisations such as the ASD AeroSME group and where possible national and regional associations and also portal organisations such as Exostar have been carried out. Feedback to these organisations on the results from VIVACE continued until the end of the project.

The assessment of the VIVACE methods covers such areas as:

- The virtual network that would support supply chains and projects of the future;
- Supply chain activities associated with design, production and cost analysis.

The work has assessed the VIVACE methods from the requirements of suppliers point of view, but also from how the "prime" and first tier will need to consider smaller company involvement.

Considerations have also been captured from the perspective of organisations delivering technical services, production capability providers and component design and make providers.



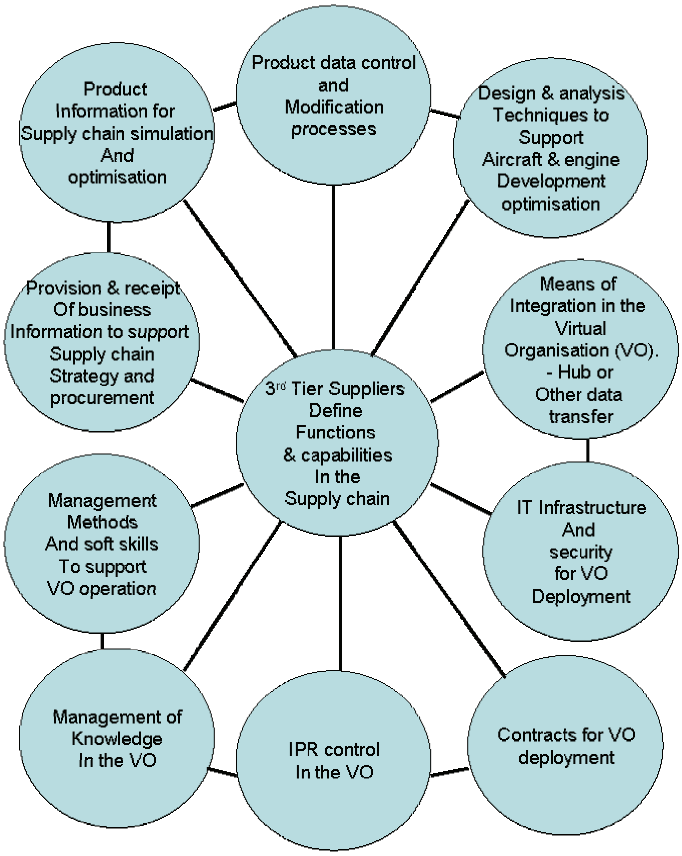
Within VIVACE, the key areas of interest are those associated with ways of working, supply chain, hub operations and virtual tools, future business environments and models and tools which support the product design and integration process.

Assessment of the VIVACE methods covers areas such as:

- The virtual network that would support supply chains and projects of the future
- Supply chain activities associated with design, production and cost analysis

Another critical area for smaller organisations which have important innovative technologies and methods, is the protection of IPR in the shared environment and increasing complex product breakdowns. This is being considered against the VIVACE environment to define the main areas of impact and the relationship to the knowledge management aspects of VIVACE.

Overall a range of issues have to be resolved to enable a supply chain operation associated with the type of business itself, e.g. technical design analysis and development, production and procurement, contractual and IPR issues and management methods, all bound together through



the IT approach and the virtual or extended enterprise.

To enable smaller companies to be involved in the future virtually enabled supply chain requires not only application of suitable integration processes and tools but also the required security environment that allows them to operate at the required security levels. This can be either through specific project based portals, or through the larger Aerospace wide portal arrangements that Sup@irworld and Exostar operate, which cover e-procurement functions as well as data transaction based functions.

To support this requires an understanding of the current methods available, and the requirements of the portals in order to identify appropriate policy and methods to deliver this capability.

Methods defined using **ISO/IEC 17799** and **27001** standards have been applied through the programme, resulting in guidelines for setting security policy, the tools that may be applicable and methods to define the security maturity of an organisation.

The most useful and important aspects of this work have been the understanding created on the third tier, but more importantly the considerations and guidelines developed which can assist in the preparation for operations within extended and virtual environments. The methods identified may be considered by organisations and procurement functions in other areas of the supply chain, not just the third tier. These provide business and management information that support the environment and technical activities related to the elements of the supply chain operations considered within VIVACE.

► Dissemination oriented toward 3RD Tier Suppliers

Specific activities are being undertaken which support dissemination. This has already commenced through the presentations completed at the Concurrent Engineering Conference ICE 2005 and 2007 and continued through the VIVACE dissemination Forums. Communications have been provided around the national and regional associations on the project to widen the knowledge of the project and in particular the results available through the website. Direct discussions have also been held with representatives of some of these groups on the programme as well. Other activities are occurring nationally or regionally as the material available for smaller companies increases. A web site dedicated to this work package has also been developed.

THE VIVACE CONSORTIUM

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THE VIVACE PUBLIC WEB SITE

The VIVACE public web site is the ultimate place to find and download:

- A detailed presentation of the project
- All VIVACE public deliverables and articles
- All VIVACE Forums presentations
- A dedicated 3rd Tier Suppliers section
- This brochure, in Adobe PDF format

The site will remain available until the end of 2012.

WWW.VIVACEPROJECT.COM

