CONCURRENT ENGINEERING DEVELOPMENT AND PRACTICES FOR AIRCRAFT DESIGN AT AIRBUS

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Abstract

Reduction of cycles (development time, series lead time) and costs along the aircraft lifecycle is a permanent priority. Concurrent engineering aims at enabling this reduction, by putting together in a multidisciplinary way of working all the relevant skills contributing to product engineering, and by setting and managing the operational conditions for work in parallel.

It is mainly a question of processes and way of working. For maximum business benefit, its implementation requires a strong sponsorship at top level, and discipline throughout the organizations, in order to define and fully apply common processes and common methods, supported by common tools.

The Digital Mock-up (DMU) becomes the heart of the product information. It is created with the support of Computer Aided Design (CAD) and is managed by a Product Data Management (PDM) system that also supports the industrial drawing release process and configuration management.

Practical operations in concurrent engineering lead to significant business benefits, which can be measured in terms of lead-time and reduction of effort in development. These benefits have now been made visible for the development of the A340-500 and A340-600, and for the A380.

As a vision, Airbus expects further integration steps in the design office technology, targeting a Virtual Aircraft, with stronger links between Systems Engineering (including Architectural Design and Requirement Based Engineering), Design to Decision Objectives around the DMU, and supported by the PDM.

1 Business context and programmes requirements

1.1 About large aircraft

A completed commercial aircraft is in many ways the compromise of the knowledge, experience and creativity of the numerous engineers involved in an aircraft manufacturers 'multidisciplinary design and production groups. But it must be also essentially the smart response to requirements coming from ever more demanding Customers, as well as from airworthiness authorities. These requirements cover safety, product aircraft performance and operational characteristics, customization, and associated response time, acquisition costs, operating and maintenance costs, environmental requirements, and others. From the business side, competition is fierce, and Airbus' approach is to offer permanently world class products and services which set the industry's standards.

Just to fix the ideas the definition of the A380 is composed of a set of about 1 000 000 drawings, which is dramatically much bigger than the number of drawings of the A340. The functional architecture of the systems is broken down into about 70 major systems, leading to several hundreds of pieces of equipment. All these definition information and data have to be managed carefully to ensure full traceability of the definition of a given aircraft against its customer's contractual requirements. This is the objective of configuration management.

The size and complexity of the product has led Airbus since the beginning to define and implement an industrial work sharing for aircraft development and series production. This has led to a high industrial specialization, with local processes sometimes, which have had recently to be harmonized to a wide extent.

1.2   Development costs and design processes

When developing a new product, the well-known comparison of the costs committed by the definition progress versus actual costs at any time clearly shows the necessity to drastically improve at the earliest the best knowledge we can have about the complete product to be developed and delivered. In the mean time, reduction of development cycle and production cycle is absolutely mandatory, to deliver better response time to market and reduce final cost of the product.

Two main features can characterize design engineering processes:

- In upstream phases (concept, feasibility, preliminary definition), processes are highly **interactive and iterative**. Degrees of freedom are numerous, and must be managed carefully in order not to be frozen too early. Work is mainly focused on architectural level, and trade-offs are frequent with a high impact on the configuration. Trade-offs between aircraft configuration and the overall design of main components are frequent. Work force in these phases is still limited (compared to the whole development workload).

- In the development phase, degrees of freedom are limited to very local design, **industrial performance** (link of engineering to manufacturing) is paramount, deployed workforce is huge to produce the definition and industrialize the product, sensitivity to operational configuration management increases dramatically.

One of the key conditions to reach cost and time reductions is to ensure that expensive development phases (detailed design, industrialization), then series production phases, are performed with maximum efficiency. This

leads also to make sure that the concept and feasibility phases, in which the large trade-offs are performed in a rather iterative manner, deliver sound baselines. As far as a design change is concerned during the development phase, the later it occurs, the more expensive it will be. Consequently, all disciplines must interact in an efficient manner, with a common objective, the successful and efficient development of the aircraft.

2   Concurrent Engineering approach

2.1   Fundamentals

The main concepts supporting Concurrent Engineering are:

- Managing complexity of the product in making it accessible to each team, then to each individual in the team. This leads to break down the product into certain "concurrent engineering products" or business objects, which represent design domains (geometrical, functional), and which enable to maximize the work in parallel.

- Synchronization, to ensure that the resulting development cycle is under control.

- Control of interfaces of the different design domains.

- Multidisciplinary engineering.

- "Break the walls", especially by developing collaborative techniques throughout the extended enterprise.

- Permanent traceability of product configuration information.

- Think process, then method and then tool. This process based paradigm implies:
  1. to really consider how design teams actually cooperate in design context, what business objects they use, how they share them, how these objects evolve as design evolves or when change occurs.
  2. to think as much as possible in terms of process integration, to streamline the overall workflow, and to maximize process quality.

Airbus has been widely investing in the development and deployment of concurrent engineering capabilities. The project, known as ACE (= Airbus Concurrent Engineering), is now a key integrator, as well as a strong vehicle of change management.

Through the significant reduction of the lead-time, concurrent engineering leads to significant cost reduction. Also, the need to share a lot of information and data with numerous users from different skills has induced the implementation of strong structuring concepts.

2.2   Synchronization through common visible milestones

A common and structured development cycle, has been developed. It is now the baseline for all Airbus programmes.

'Fig.1. A common view of development milestones'
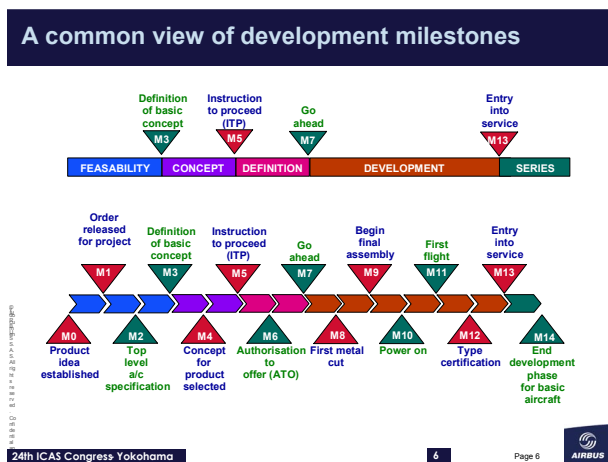
This common development model is broken down into **five major phases**:
- Feasibility (M0 – M3).
- Concept (M3 – M5).
- Definition (M5 – M7).
- Development (M7 – M13).
- Series (M13 – M14).

Typically, in a programme, the ramp-up of resources takes place after M5, and even more significantly after M6, when the complete set of drawings has to be produced and delivered, when tooling has to be designed and manufactured.

Each milestone is described in terms of expected engineering content, and thus the engineering work is specified in a visible and shareable manner. Even though in the actual implementation there can be some tuning (due to programme specifics), this gives a strong framework for development organization, work structure, and planning.

2.3   The Digital Mock-Up (DMU)

Practically, even if it does require new generation powerful tools, concurrent engineering is not just a tool problem: it is firstly a question of technical processes and work organization, from which dedicated methods and tools have to be developed.

'Fig.2. DMU'
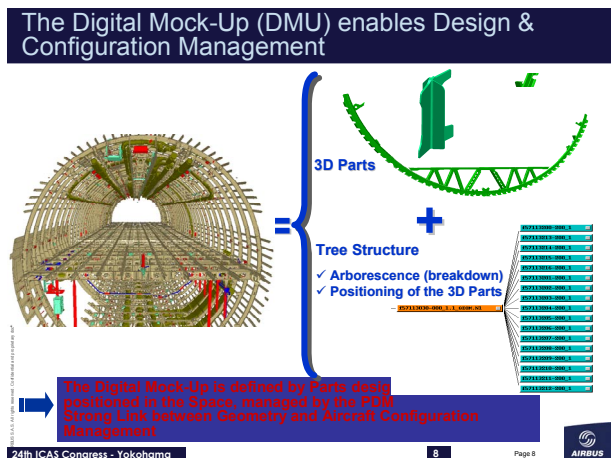
As already mentioned, concurrent engineering means that design engineering teams are working in parallel. This makes sense only if they know at each time the status of the product they are working on, which means to enable a sharing of the information, according to the different needs of the users.

It also appeared quickly that this approach led to define several "design products" representing the aircraft; these design products being actually large information objects. One can also consider each of these design products as one perspective or point of view relevant to certain needs. And since the objective of design engineering is mainly to produce data for manufacturing, this package of design information is called **Digital Mock-Up (DMU)**.

The DMU is consequently defined as an organized set of information, reflecting the different needs of the design teams, and structured according to a **Product Structure**. The Product Structure is mainly the core structure describing and managing how the drawing sets (when considering the output for manufacturing) are organized. It is also one of the key enablers of Configuration Management. From a technology perspective, the DMU relies on techniques similar to Virtual Reality. Thus it is possible to "navigate" in the DMU, to explore selected design areas.

The DMU is composed of several design products: each of these products is used to satisfy the engineering expectations of the different teams along the product lifecycle. For instance:

- The **Master Geometry** resulting mainly from the definition of the aerodynamic shape of the aircraft can be used by the structure design team to derive a preliminary definition of the structure and associated design principles, by the manufacturing engineering teams to have a preliminary definition of the final assembly line operations and building, and by the operations engineering teams to study the servicing capability at the airport.
- The **Space Allocation Model** enables the systems engineering teams to perform the pre-installation of systems and various pieces of equipment. It also enables the design supportability teams to assess how the maintenance operations can be performed.

- Eventually, the **Definition Model** is the final stage of the DMU, from which the data for manufacturing is derived.

Some of the other DMU products are: the Design Principles, the Frontier Models, the Stress Design Reference Base, the Systems/Equipment Installation Requirements Dossier.

The concepts of Master Geometry and Space Allocation Model also apply to tooling.

The DMU is now the central tool between the different engineering teams, and also a fundamental dialog tool between Engineering and Manufacturing.

'Fig.3. Development process'
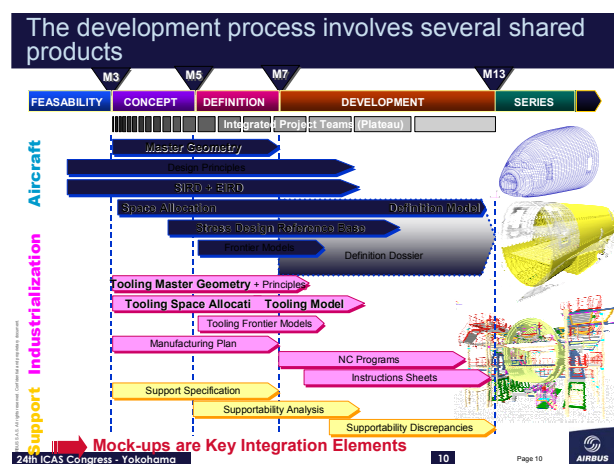
2.4 Way of working, new jobs

2.4.1 Working around the DMU

As a consequence, concurrent engineering has placed the DMU at the heart of the technical quality of the design process. It has been necessary to establish around the DMU the appropriate technical control processes. This is mainly achieved through the DMU reviews. Held at regular time periods, the DMU reviews allow progressive validation of the product design thanks to the participation of the multidisciplinary teams.

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It is a strong contribution to the business requirement to get it right first time. Using the DMU enables also to suppress the development and use of expensive (in time and cost) physical mock-ups.

2.4.2 DMU integrators, DMU Data Quality

The DMU is quite a complex engineering object, and requires proper management. Otherwise all benefits of concurrent engineering are lost, there is a risk of more manual work (and hence limited cost reduction, risk not to meet programme milestones), or even worse loss of baseline.

Therefore Airbus has defined and implemented the skill of "**DMU integrators**". In each component design and build team there is now one or several DMU Integrator(s), whose job is mainly:

- To ensure the validity of the data composing the DMU, especially those related to configuration.
- To perform problem analysis and ensure the correctness of the DMU (especially after integration phases), e.g. to check that there is no "hole", no erratic data, to identify the first clashes.
- Hence, to contribute to design process quality.

Airbus has consequently also defined and implemented a new skill: **DMU Data Quality Management**.

2.4.3 Development plateaus

Implementation of concurrent engineering has led to organize the design teams in plateaus. In the plateau concept, teams from different skills (such as Engineering disciplines, Manufacturing, Customer Services, Procurement…) are co-located in proper collaborative environment for rapid and efficient communication and decision-making. Every involved discipline is the carrier of his/her home competence, and the validation and decision-making process is properly defined. The plateau is also the place where during the definition phase of a programme,

risk-sharing subcontractors are co-located with Airbus teams to optimize the specification of their work package.

3 Key enabling technology: Computer Aided Design (CAD), Product Data Management (PDM)

3.1 Computer Aided Design (CAD)

The CAD technology now enables us to support a complete product process from the first pre-design concepts in the design office to the detailed programming of the numerical controlled machine for the manufacture of basic parts. This leads to the concept of Integrated Technological Process (ITP).

Designing in 3D is not only managing pure geometries. It is mainly the way to ensure that the parts are designed as a whole, in a holistic approach, integrating and managing functional requirements or constraints (e.g. interfaces, holes, clearance requirements, parametric definition).

Knowledge Based Engineering (KBE) applications: embedding more knowledge (and managing this knowledge in configuration) into the CAD system, and hence creating a seamless CAD + KBE package, delivers more and more collective benefit, and contributes to industrial processes quality.

ITPs can be envisaged for all product/part families of an aircraft, such as: sheet metal, machined parts, composites, piping, tubing, and electricity.

It is not the intent of this paper to detail CAD technology, since numerous references address the matter.

3.2 Product Data Management (PDM)

The PDM is the operational and neuralgic engine of the aircraft development and definition. It enables especially:

- At DMU level:
  - The management of the **product structure** (that is the way the set of

drawings is organized and how the drawings are released to manufacturing).

- The vaulting of design data.
- The integration of the DMU.
- The visualization of the complete product DMU according to its actual configuration status.
- The access by the design teams, provided appropriate authorizations (particularly in case of the extended enterprise) and subscriptions are defined, to the DMU.

- At industrial process level:
  - The management of the change process (either during a development phase or in a customization phase).
  - The validation and application of the different configuration (effectivity management) according to the customers' requirements.
  - The link with the Enterprise Resource Planning system.

4 Concurrent Engineering implementation

4.1 From theory to practice

Developing and implementing concurrent engineering techniques is not a minor task. It is a deep change, impacting several operational functions of the company. Like any other high added value developed product, concurrent engineering capabilities deliverables must absolutely be thought as "**users oriented**".

4.1.1 Overall approach

The overall implementation approach considers the following phases: development, deployment, and operations.

These phases are not sequential and themselves obey concurrent engineering principles! Development and deployment are in strong interaction. Deployment and operations have to be smoothly managed to avoid any handover transition problem.

4.1.1.1 Development

During the development phase, users' needs are captured, processes re-engineered, as far as needed, these needs are transformed into capabilities specifications, and the tool related parts are transformed into software/hardware specifications, which are then developed and tested.

4.1.1.2 Deployment

The deployment phase consists in making the capabilities available to their users, after having verified the specifications, tested in actual operational environment, ensured training of users, ensuring the first operational accompaniment in support to the users.

Deploying concurrent engineering capabilities is subject to the definition of deployment roadmaps, in order to take into account:

- The current "equipment" of teams (currently operational concurrent engineering packages, information system and IT environment).
- The necessary level and quantity of training.
- The business context, and its suitability or criticality to experience a migration.
- The costs and scheduling of deployment.

4.1.1.3 Operations

When the capabilities are deployed, the design teams on the plateaus have to operate with the DMU. They are supported by CAD/PDM support teams, very close to the users (by their knowledge of design processes, by their physical collocation on the plateau). It is generally considered reasonable to have one support head per fifty design heads in steady regime. Learning phases induce sometimes (particularly when significantly new functionalities are deployed) to a higher ratio.

4.1.2 Implementation and transformation management

High-level sponsorship is required: implementing concurrent engineering (even for

organizations having a certain experience in the matter) remains an important change in a company, and requires buy-in and full support from top operational management.

Managing properly this transformation is key for the success of a deployment.

The **human dimension** is also key: it is necessary to reduce and win against the natural resistance to change. When different cultures are present, this human dimension increases significantly. Finally, it is necessary to train (of course at various degrees and depth) a wide variety of staff (from very specialized operational training for designers, to high level awareness and associated managerial strategies for top management).

This requires **regular communication**, to create confidence and enable win-win situations.

4.2   A340-500 and A340-600 programme

The implementation of concurrent engineering for the A340-500 and A340-600 programme has practically resulted in dramatically improved performance:

- The development effort has been drastically reduced, enabling especially an easier and faster assembly of the central fuselage section.
- The overall development lead time has been reduced by about ten months.
- Costs have been consequently significantly reduced.

4.3   A380 programme

For the A380 programme, aircraft components management teams are transnational: Airbus has deployed concurrent engineering capabilities at all Airbus sites. About 1800 workstations fully equipped with CAD/PDM capabilities are deployed in the company.

To enable the exchange of the DMUs between the different sites, dedicated processes have been established: since the DMU Exchange (DEX) contributes to development team performance, it has been instrumented with

performance indicators, and is consequently tightly monitored.

As a result of the extensive deployment of concurrent engineering, the assembly of Main Components Assemblies has been made easy, and the development is reduced.

The programme is now in its production ramp-up phase: concurrent engineering capabilities support the customization process, especially with the help of the management of a Configured DMU.

5   Research approach and vision

5.1   Research projects

Practical implementation of concurrent engineering in our aircraft programme operations has been made possible only after a continuous research effort. Step-by-step, research has allowed an implementation in aircraft programmes.

A large part of these research projects have been performed in co-operation with other aeronautics partners (airframe, engine, systems), aerospace partners, research institutes, and universities, but also sometimes in wider cooperation schemes grouping other industries, such as the automotive industry.

Part of this research has been or is carried out in the framework of very large projects (see here below ENHANCE and VIVACE), enabling a much wider consideration of needs and opening the way to wider dissemination for better overall efficiency.

5.2   ENHANCE

With the ACE initiative, Airbus has firstly focused on the improvement of its internal performance. During the development of the A340-500 and of the A340-600, the way has been opened to the deployment of concurrent engineering techniques to the supply chain. But in an industry where about 60% of the product value comes from suppliers, there was evidence that research should be carried out to really design concurrent engineering capabilities for

the extended enterprise. This was the aim of the ENHANCE project (= **ENH**anced **A**ero**N**autical **C**oncurrent **E**ngineering), which has put together for three years (1999-2002) more than 50 partners: airline, aeronautical industry (aircraft, helicopter, engine, equipment manufacturers), research institutes, information technology vendors. ENHANCE delivers outstanding results through pilots in:

- Aircraft products development processes.
- Product data models enabling future multi-view description and management of the product.
- Collaborative ways of working and supporting tools for the Extended Enterprise.

5.3 VIVACE

With VIVACE (**V**alue **I**mprovement through **V**irtual **A**eronautical **C**ollaborative **E**nterprise), some 50 partners from industry and research institutes will cooperate during four years (2004 to end 2007).

'Fig.4. VIVACE'
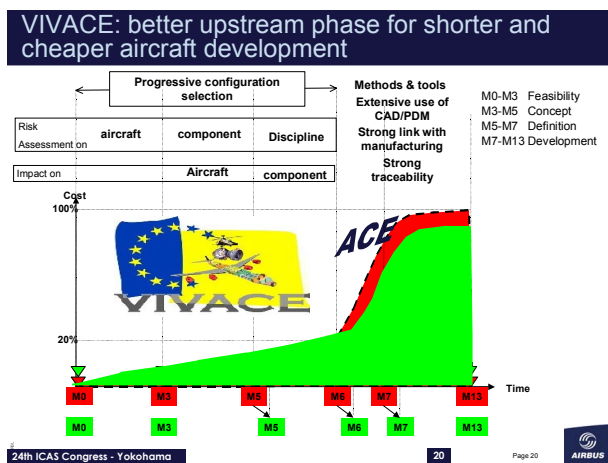
The project focuses first on the development upstream phases, and will bring solutions to have "better" pre-definition phases (where costs are still relatively limited), for cheaper overall development costs. This could be achieved through a slight increase of the pre-definition phases, but with a reduction of the detailed definition and development phases.

The project will address:
- Simulation techniques (aircraft, systems, main components).
- DMU and concurrent engineering.
- The extended enterprise.
- Decision-making supported by knowledge management.

5.4 Vision

To support its vision in engineering capabilities for aircraft development, Airbus has been developing the concept of the Virtual Aircraft, based on a consistent and structured approach of Architectural Design, and the continuation of concurrent engineering initiatives in a perspective of more integrated Product Lifecycle Management (PLM).

This model can be summarized as depicted in the figure below:
- Targeting ever better to meet Customers' requirements, with the support of:
- A **Virtual Product** system, and
- A **Virtual Enterprise** system.

'Fig.5. The Virtual Aircraft'
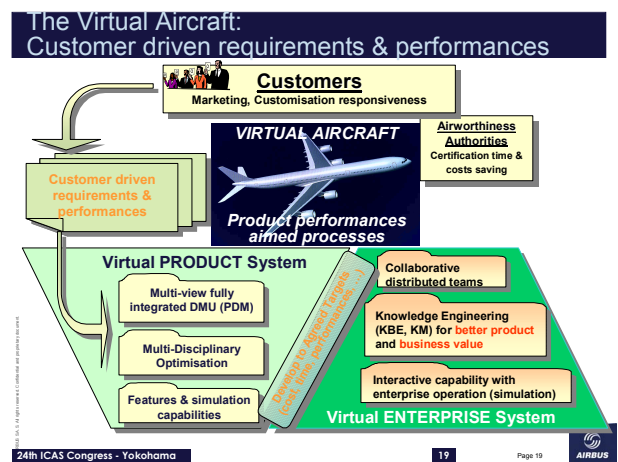
The main implementation axes of this vision are:
- Deployment of System Engineering techniques.
- Develop to Agreed Targets and Product Performance Driven Processes.

- The development as early as possible of a maximum of simulation capability (including virtual reality) in order to have at the earliest the best architecture and definition of the product as a response to the programme requirements.
- A fully integrated and multi-view DMU, and associated PDM.
- Extensive development and deployment of Integrated Technological Processes.
- The continuation of development and extensive implementation of Knowledge Based Engineering techniques, enabling the delivery of best value of engineering competence, focused on high added value tasks.
- Optimized Knowledge Management processes and capabilities.
- A fully integrated extended enterprise and supporting information system, with high performance collaborative working capabilities.

6   Conclusion

In recent years Airbus has been continuously developing and implementing a policy regarding the development and deployment of concurrent engineering capabilities. The knowledge, the practical operational experience and the understanding and management of human aspects gained during the recent aircraft programmes has delivered significant business benefits.

Airbus also manages a structured research approach, enabling to build-up and secure the definition of a pragmatic but ambitious vision, and allowing consequently its progressive implementation into business operations. Opening these research initiatives to a wide partnership eases the deployment of these practices throughout the aeronautical industry.

References

[1] ENHANCE website:
     http://www.enhanceproject.com

[2] VIVACE website:
     http://www.vivaceproject.com