CHALLENGES IN EUROPEAN AEROSPACE
5TH CEAS AIR & SPACE CONFERENCE

INTEGRATED MULTIDISCIPLINARY ENGINEERING SOLUTIONS AT FOKKER AEROSTRUCTURES

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Abstract

As a tier 1 supplier, Fokker Aerostructures needs to be able to quickly respond to market demands from aircraft integrators. To distinguish itself in the current competitive market environment, Fokker needs to be able to rapidly respond to new product opportunities and apply innovative technologies in the offered solutions, resulting in more lightweight designs that can be manufactured at lower cost. To achieve this, design automation and optimization techniques are being developed to perform detail design studies, incorporating more requirements to a higher level of detail. These studies form the basis for simplified decision making models that allow short operational design lead times and multidisciplinary design optimization. Fokker currently conducts two research projects that address the challenges above: TAPAS2 and Rudder in a Month. Both these projects have shown that the Fokker vision for a new aircraft component design are valid and achievable. However many obstacles need to be overcome. These mainly consist of better more mature software tools and better and more transparent storage of the knowledge used in these software tools. Finally social change is required to make the current generation of Aerostructures engineers accept the radical changes to the design process.

1 Introduction

Fokker Aerostructures is a Tier 1 supplier of aircraft structures for many of the major aircraft integrators. Fokker usually operates on the design and build principle. Meaning that the company is responsible for both the design of a structural component and its manufacturing. Fokker has designed and manufactures the tails of the Gulfstream G650 and the Dassault F5X, as well as the outboard Flap of Airbus A350. Fokker Aerostructures is part of Fokker Technologies which also consists of companies involved in aircraft wiring and aircraft maintenance.
Fokker's main areas of expertise are Fibre Metal Laminates (FML), metal bonding , thermoplastic and thermoset composite. Fibre metal laminates are found in the fuselage construction of the Airbus A380 and consist of alternating layers of Aluminium and fibre glass composites. Thermoplastic composites consist of carbon fibres in a matrix consisting of thermoplastics, for example PPS. In recent years Fokker has developed the tail movable of both the Gulfstream G650 and the Dassault F5x in using this material and won the JECC 2013 award for the construction of the Agusta Westland AW169 horizontal tail plane.

Because Fokker is responsible for both the development and manufacture of aircraft components it deals directly with the aircraft integrator. The latter are increasingly asking for more affordable, meaning cheaper, components developed in a shorter lead time. It is increasingly difficult to meet these requirement using the standard development process. Therefore Fokker proposes a design process in which automation and optimization are incorporated as much as possible, and development issues are addressed as multi-disciplinary problems.

In this paper the vision of Fokker for its future design process is described. The second section gives insight in the actual problems encountered and Fokker's vision on how to address these problems is described. In sections three and four case studies conducted at Fokker give an insight in how this vision is translated to the real world. Finally in section five and six the requirements for systems supporting this new development vision are discussed and conclusions are drawn.

2 Problem description and Fokker vision

In the aircraft industry today the focus is on incremental growth and disruptive growth (Figure 1). This means that technical progress on the aircraft level is not high but that improvements are found by providing customers with more value through technology improvements on a lower level. This can for example mean introducing new engines (Airbus A320 NEO) or providing laminar flow tail surfaces (Boeing 787-9) for more fuel efficient operation of aircraft.

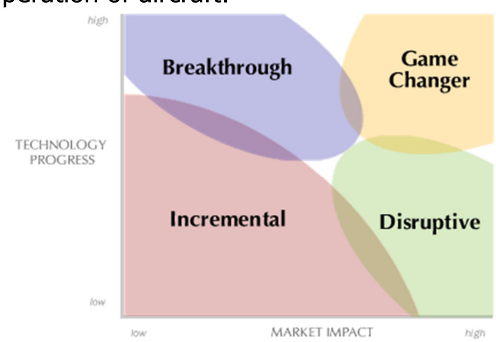

Figure 1 Development areas of the aerospace market

Incremental improvements are only viable with low cost and short time to market. The reason for this is that the value for the customer is limited so the price this customer is willing to pay is also limited. Furthermore incremental improvements must have a short time to market to ensure the value advantage with respect to the competitor can be realized.

For Fokker the tendency towards incremental growth provides both opportunities and challenges. First of all aircraft integrators are constantly looking for opportunities to improve their existing designs. There is therefore ample opportunity for Fokker to apply its unique technologies on existing aircraft types. The challenges are that Fokker competitors are also aware of these opportunities and can therefore try to replace Fokker components on existing aircraft with improved designs. To overcome this there is an continuing pressure to improve existing components either by increasing performance (e.g. weight reduction, improved aerodynamics) or by reducing their cost.

As was stated before, new aircraft component designs and design concepts need to be affordable. Therefore the non-recurring cost of a new aircraft component must be kept low to reduce the influence of sale price by amortization. There are several aspects of non-recurring cost but the most significant one is the development cost. Therefore it is essential to keep this development cost low.

The current practice for the development process within Fokker is to apply a so-called concurrent engineering process (Figure 2). This means that development phases are run concurrently. This has the advantage that the development lead time is shorter than the traditional sequential development process. However by having the different phases run concurrently inefficiencies are introduced in the development process. For example assumptions need to be made because certain requirements are not clear when a design is made. When those assumptions prove to be wrong a re-design is required, which incurs extra cost.

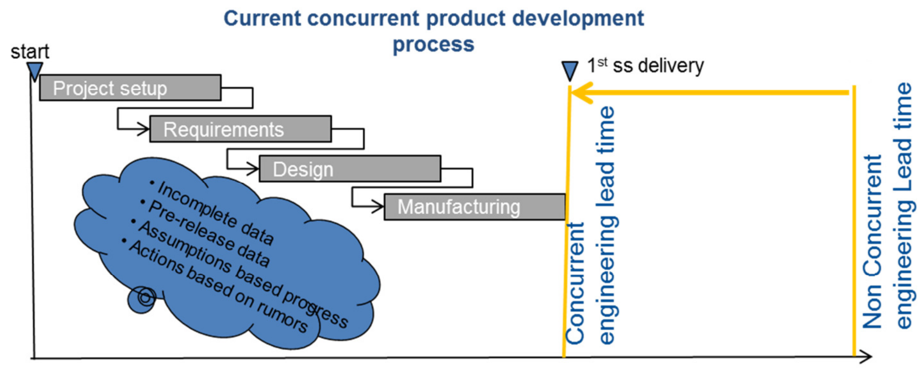

Figure 2 Concurrent development process currently used at Fokker Aerostructures

To ensure Fokker Aerostructures can remain competitive and offer competitive non-recurring cost figures a radical rethink of the design process is required. Fokker proposes a design process where front loading and virtual prototyping play an important part. Front loading was described by Thomke and Fujimoto [1] as "*a strategy that seeks to increase development performance by shifting the identification and solving of design problems to earlier phases of a product development process*". For Fokker, front loading means developing engineering knowledge before the earliest phases, i.e. before the actual design process starts. This is achieved by capturing product knowledge from earlier projects and use this engineering knowledge to rapidly evaluate many design variants covering different requirements sets. During the actual design process this evaluation of design concepts is continued. In the process it is the goal to achieve full maturity of each of the design concepts evaluated. This ensures that no time-consuming changes are required once a design concept has been chosen. With this, both approaches for front loading presented by Thomke and Fujimoto are applied in the design process: transfer of knowledge between projects and rapid problem solving.

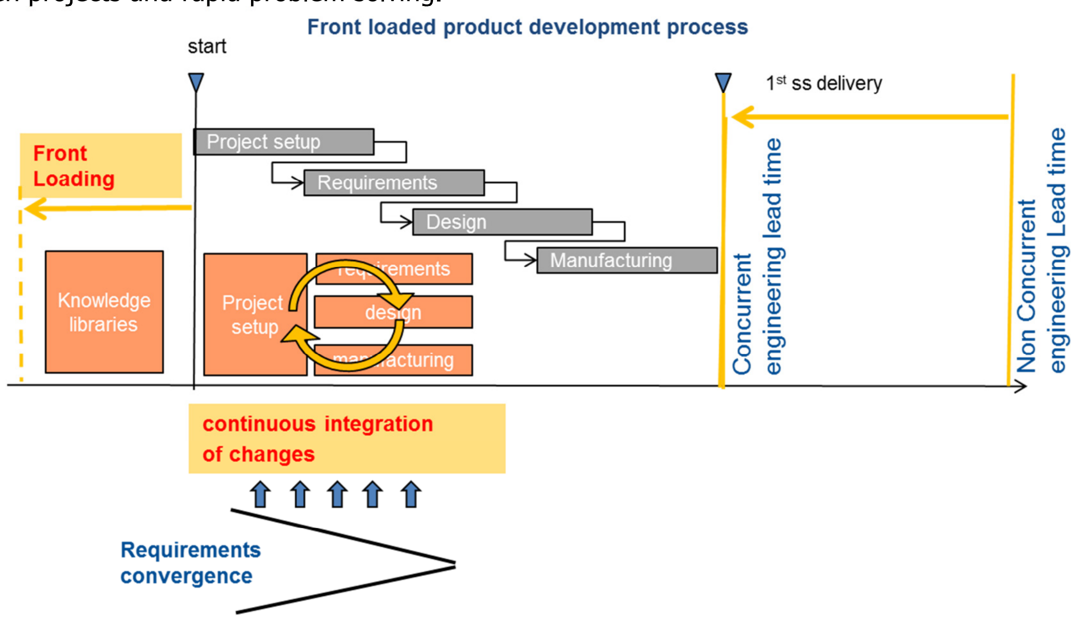

Figure 3 Proposed future development process with front loading implemented

The front loaded design process can only work when the design concepts can be evaluated quickly and completely. To be able to do this while keeping non-recurring cost down the cheapest employee needs to be used, this is of course the computer. In the proposed development process each design concept is fully developed and analysed however it will not be manufactured in a physical sense. Therefore this practice is called virtual prototyping (Figure 4).

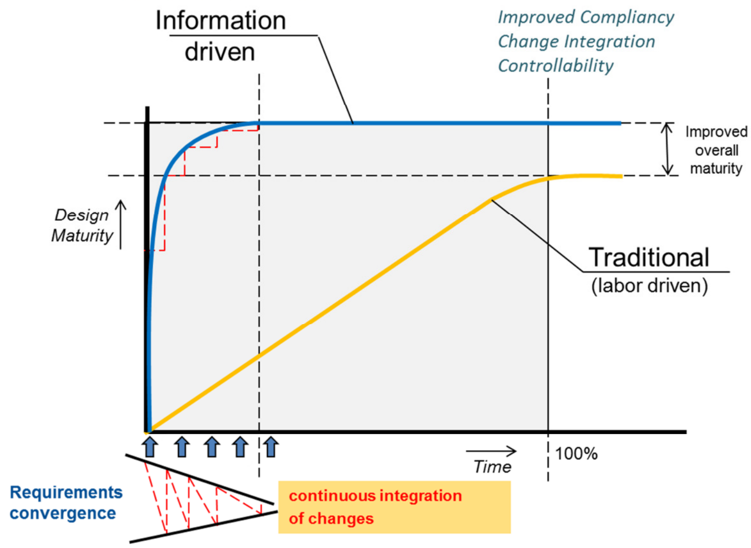

Figure 4 Design maturity achieved in the front loaded design process using virtual prototyping

In order for virtual prototyping to work the analysis of a design concept needs to be as complete as possible. For this analysis we can use well known engineering techniques such as KBE (Knowledge Based Engineering) and MDO (Multidisciplinary Design Optimization). While these techniques have been used for several years now and have provided satisfactory results both in industry [2][3][4]and in academia [5][6], application in a front loading scenario requires them to handle the complexity and uncertainty of the aircraft component design process.
Because the design concepts are completely analysed in the front loading scenario, a high maturity is achieved quickly. This ensures that development setbacks can be identified quickly and allows a better response to changing requirements. Because the influence of changes at a higher level on the design of an aircraft component can be quickly analysed it allows a Tier 1 supplier like Fokker to provide active feedback to the development cycle of the Aircraft integrator.
In order for the front loaded development system to work using virtual prototyping the following automation elements are required:

1. **KBE systems**. KBE systems provide the possibility to automatically create product models including geometry and associated engineering data based on formalized engineering rules. Because many of the engineering problems are geometry based, KBE systems are essential to find possible solutions.
2. **Workflow managers**. In order to automate the engineering process many smaller processes need to be linked and the information needs to be transported between the tools used in these processes. This requires a workflow manager. This workflow manager must be able to monitor the status of the information in the system and must also allow for human interaction where required. Different workflow management may be required for different process levels such as business process management and simulation process management.

3. **Multidisciplinary Design Optimization (MDO) tools**. To achieve the best possible solution the solution needs to be optimized. This has to be done in an intelligent manner because of the total complexity of the problems, it is impossible to evaluate all possible solutions. Multidisciplinary Design Optimization tools providing design of experiments and numerical optimization techniques should be used for this.
4. **Robust design tools**. In the front loading scenario not all requirements are known or frozen during the design. In order to be well prepared for a development request the sensitivities to requirement deviations need to be known. For this purpose tools are required that can evaluate the robustness of a design solution linked to variations in the requirements set.
5. **Data management**. Product data and standards must be controlled and made available without the need for duplication according to the single source of truth philosophy. Various systems such as Product Data Management (PDM) and Simulation Process Data Management (SPDM) systems may provide solutions for this.

With the automation elements described above, the front-loaded development process can be executed. However for the system to be a success another change is also required which is not technological. This is the change in the engineers attitude and behaviour in the development process. In the current development system engineers are classified into different categories such as design, stress or manufacturing. In the new system engineers must be able to think multidisciplinary and be able to judge the results that come from the various multi-disciplinary system analyses. Furthermore engineers will need to accept that the computer will take a lot of their work out of their hands. Of all the changes required the social change required to implement the described vision might well be the most difficult to achieve.
To achieve the required social change and to ensure trust in the developed design tools it is imperative that the rules used in the tools and its results are transparent. This means that the rules applied must be made accessible. Furthermore intermediate results must be viewable by the engineer. This ensures the engineer can assess the quality of the intermediate results and compare them with the results expected based on his experience.

The development system proposed in this section has not been implemented in commercial projects within Fokker Aerostructures. There have been some pilot projects where aspects of this vision have been addressing. In the next sections two of the projects will be discussed: TAPAS2 and Rudder in a Month.

3 TAPAS2 case study

TAPAS2 is a multi-company project aimed at developing thermoplastic composite technologies. One of the aspects in the research is the actual application of thermoplastic composites in real life structures. To be able to judge the competitiveness of thermoplastic constructions an assessment of the manufacturing cost and the weight of these kind of constructions compared to more traditional designs needs to be performed. To do this, a toolset is developed that can assess the weight and cost of an aircraft component. The focus of this toolset are wing box like constructions such as aircraft wings, tails and trailing edge movables.
The developed toolset is a combination of existing tools and newly developed tools. These tools are provided and also located at different companies throughout the Netherlands and integrated using an integration framework (Figure 5).
The toolset is focussed on the proposal phase of the development process, meaning that with limited information about a component, usually an Outer Mould Line (OML) plus some additional aircraft related information, a design concept has to be devised. Obtaining a high-fidelity evaluation of the design

concept is critical for the proposal phase, as decisions taken determine the profitability of the program for years to come.
This paper focusses on the tools developed at Fokker and the integration between the tools. The TAPAS2 toolset was not developed with the Fokker vision of Front Loading from the outset, however with some adjustments it will fit neatly.

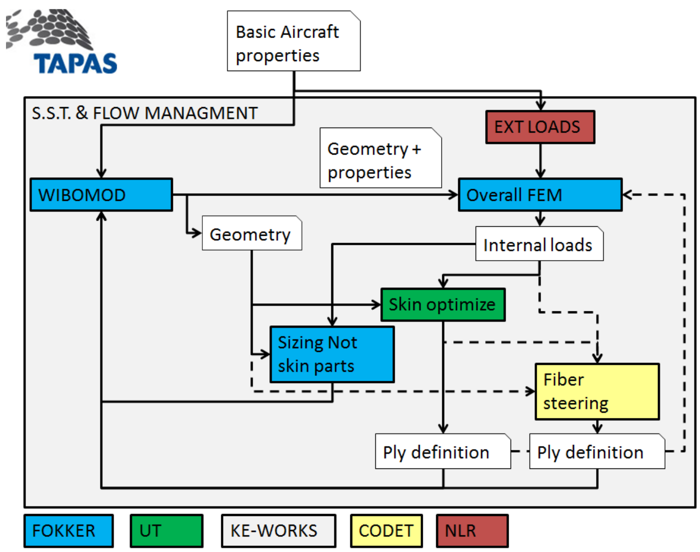

Figure 5 Tapas overview including the partners involved in the project

From the picture above it might appear that the analysis sequence of a wing box like part is relatively simple. However each of the boxes in the figure represents multiple analysis tools and multiple interfaces between analysis tools. Often these analysis tools are also located in different locations and operated by different companies. Because of this the interfaces in the TAPAS2 framework are explicit meaning that they are files flowing from one tool to another and no direct communication between tools. In this way the information form can be made more manageable. It also allows for the simple replacement of tools in case they get obsolete.
The information flow throughout the system will be managed by KE-chain which is a work flow and data management system currently under development at one of the partners. The need for such a system is illustrated in Figure 6 which gives an insight in the number of tools and interfaces of this relatively simple system.

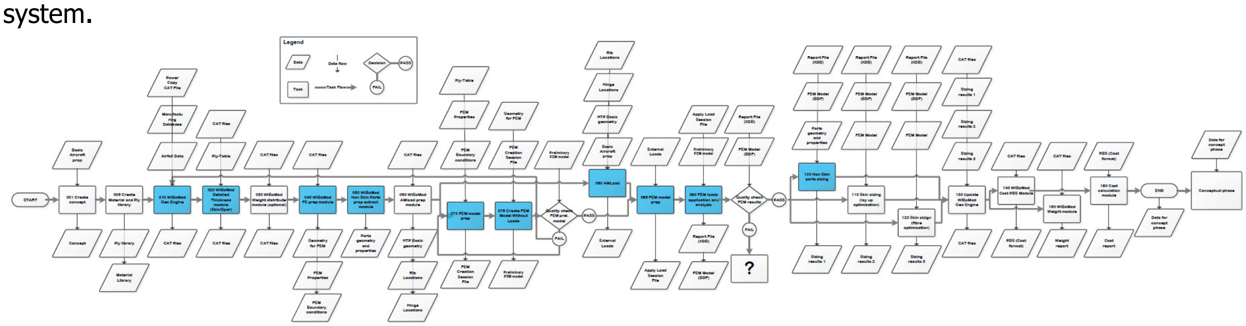

Figure 6 Tapas 2 development workflow

At the heart of the tool set is the so called model generator. This model generator generates a parametric model of wing box like structures. This model generator has been described in detail in [7], in this section a short description will be given. The modelling engine core is called WiBoMod for Wing Box Modeller. It is programmed using the Visual Basic for Applications (VBA) interface of Catia V5. Using this interface a completely linked and parametric model of a wing box is created. The model is not very detailed and consists only of the main structural elements like spars, stringer, ribs, brackets and skin panels. These main structural elements are represented by a basic geometry plus a set of parameters.

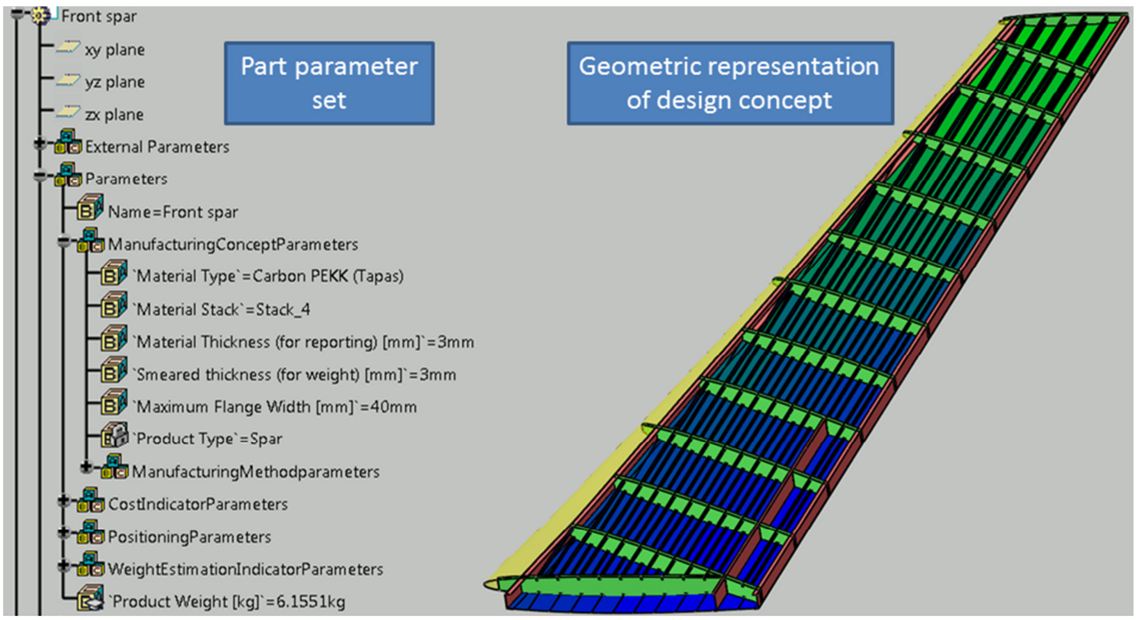

Figure 7 Overview of the parameters and geometry created by WiBoMod

The set of parameters captures the non-geometric information that is required to determine the manufacturing cost and weight of the component. This information is for instance the material from which the part is made, the manufacturing method used etc.

On top of WiBoMod several add-on modules are created these enable the user to provide other data to the system such as a Product Breakdown Structure (PBS) and also gives the user the possibility to extract information required for other analyses. These extra analyses are required to determine the cost and weight of the design concept.

The cost analyses are performed by in house Fokker Aerostructures tools. Because WiBoMod was initially developed only to fill these tools the WiBoMod data set contains all the information required for the cost analysis. Main elements in these analyses are Fokker Aerostructures proprietary cost codes.

For determining the weight of the aircraft component a sizing is required for all the aircraft parts. To be able to perform a sizing first the internal stresses in the construction need to be determined. This is done using a Finite Element (FE) Model. For this FE model 3 elements are required. Firstly the geometry of the component must be created, secondly the properties of the parts must be specified and thirdly loads must be applied.

The geometry is prepared for FE analysis by using an add on module to WiBoMod. This add on module cuts up surfaces that represent all the parts such as ribs and spars into smaller surfaces. These surfaces are always 4 sided and the module also ensures there are no "T-junctions". The method of achieving this is described by [8]. The surfaces created in his way can be easily meshed.

The properties of the parts are exported to an XML format. This XML contains all the material information required plus geometric information, such as surface corner points, that are required during the FE model generation process.
The loads applied are determined in a loads determination tools based at the NLR (Dutch Aerospace Laboratory). This tool is able to determine specific load cases based on general aircraft properties. This is a key enabler for front loading because it allows for the design of a component without the specific load information known only by the aircraft integrator. The loads are provided to the system though an Excel file.
The Geometry XML file and loads Excel file are used to create a FE model. In this case the FE package used is Patran. This FE package can be automated using so called session files. These are basically text files containing instructions to the program. For TAPAS a tool has been created that can generate the session files and thereby automate the generation of the FE model.
Once the internal stresses are determined using the FEM Model the actual sizing of the parts can begin. At Fokker there are numerous tools used for sizing. However usually these tools require a level of human interaction. Within TAPAS2 the goal is to eliminate this interaction as much as possible and integrate these tools in an automated system. Currently one sizing tool has been implemented for demonstration purposes.

The resulting workflow is shown in Figure 8.

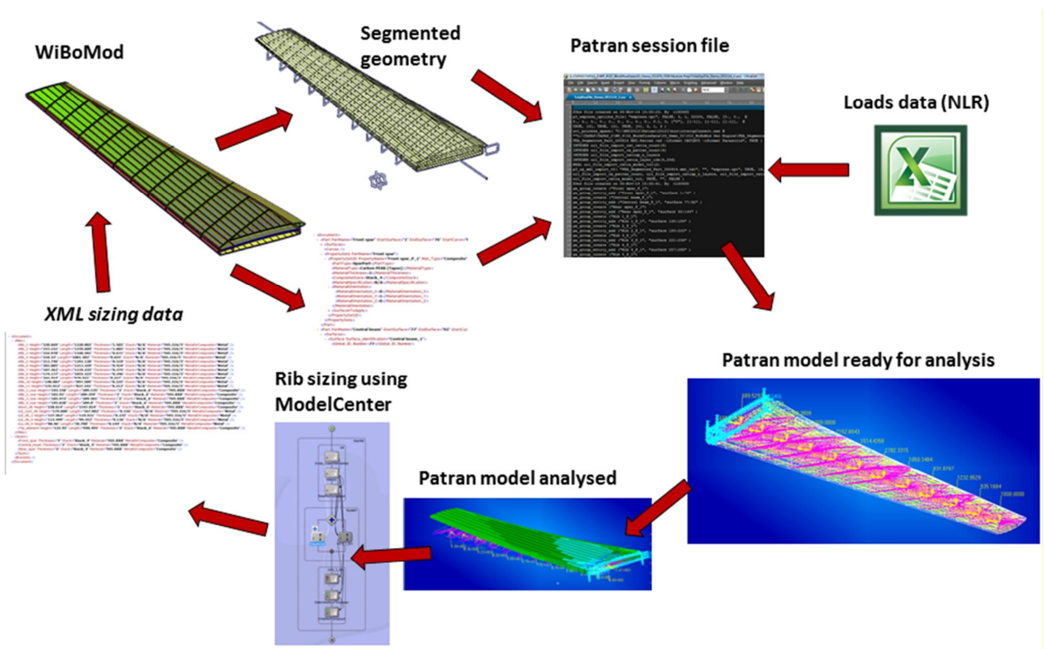

Figure 8 Implemented TAPAS2 analysis flow

Within TAPAS2 the items to be used in an automated system have been demonstrated. However many challenges remain. These will be tackled in the next 2 years, focussing on introducing more elements from the front loading vision into the system. The main challenges that remain are:

1. **Availability of sizing methodologies***.* WiBoMod data detail level is not enough to feed sizing tools and methods currently used at Fokker. Solution for this will be to increase the fidelity of the WiBoMod models or to develop lower fidelity sizing tools and methods.

2. **Model and software robustness***.* Current tools and models created by the tools often crash when used outside the intended design space. Solution for this will be development of better error handler functionality and better describe the supported design space.
3. **Openness of IT infrastructure***.* The TAPAS2 tool flow requires that tools on different servers can be run and that data can be exchanged between these servers. However often proprietary tools are used and furthermore servers are protected by firewalls. These issues get in the way of the use of tools and transfer of the data between the tools. Solution for this will be to look at different architectures that better support the requirements of the TAPAS2 development flow.

4 Rudder in a Month case study

Rudder in a Month is an internal Fokker process improvement program aiming at discovering and developing techniques to realize the vision of the Front Loaded development process. The objective is to develop an aircraft rudder within the timespan of a single month to a level that corresponds to the normal results of the full-scale development (FSD) phase up to the critical design review (CDR). Such a development process would take about two years using current methods.

4.1 Development approach

To obtain solutions for the many aspects of the front loaded development process for a rudder, an agile development approach is applied in which both the product scope and the technology scope are increased iteratively. With respect to the front loaded process, the anticipated development sequence is indicated in Figure 9. Development will start with obtaining the means to automate the development process during the detail design phase and demonstrating it (1). The detail design tools will be applied to perform virtual prototyping, explore relevant design spaces, improve design and analysis methods and standards (2). Potential design simplification opportunities are identified to define higher level solutions to enable MDO (3). The tools and standard libraries are then used in an actual development program in order demonstrate the achieved reduction in lead time (4).

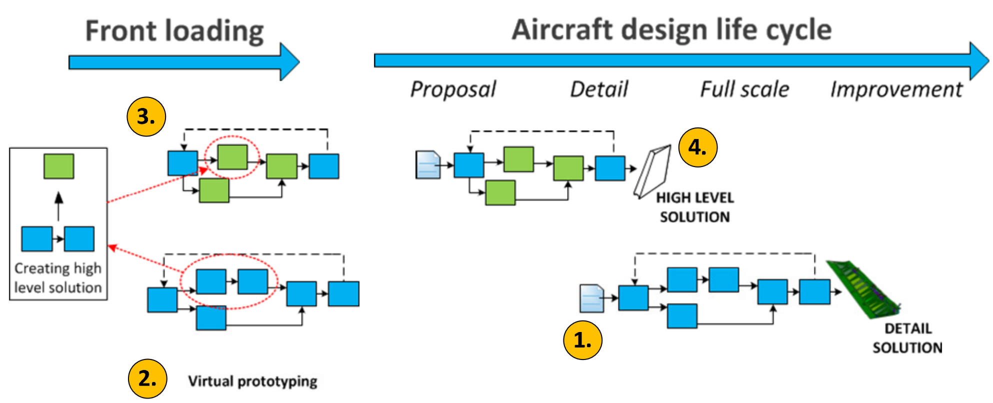

Figure 9 Development approach towards a front-loaded engineering process

4.2 Phase I – hinge design

As the overall scope of the Rudder in a Month program is vast, the first phase was aimed at a somewhat narrowed product and process scope. As the interface elements of a rudder are often driving the design, the design of a sliding hinge was taken as product scope. The engineering process scope was set to the evaluation of a detailed design to its requirements, the generation of CAD models and requirements compliancy reports (for stress, weight and cost). Where the TAPAS2 project toolset is geared for proposal

phase design definitions, the toolset for the RiaM first phase was required to be at the detail design level. This corresponds to the features required in the lower-right corner of Figure 9.
The hinge system of a rudder typically consists of a set of hinges that can be clamped or sliding, fail-safe or no. Figure 10 shows a schematic illustration of a sliding hinge consisting of a bolt, nut, bearing, bushes and lugs. Given the part identification or dimensions of each of these components the objective is to determine whether the hinge complies to requirements and by what margin. The main constraints are the rudder OML and the loads applied to the hinge, taking the desired margin of safety into consideration. The results are reported in the form of certification document style Excel and Word files.

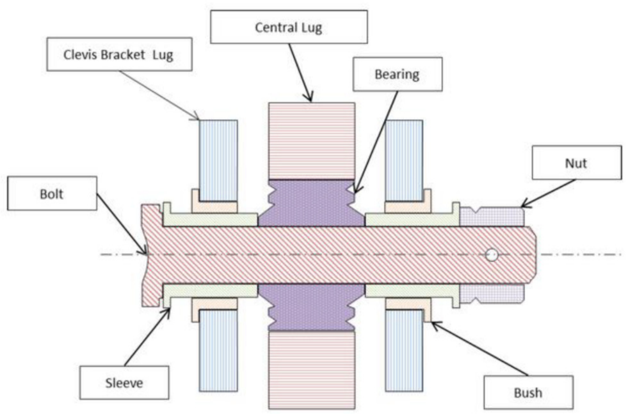

Figure 10 Schematic illustration of a sliding hinge

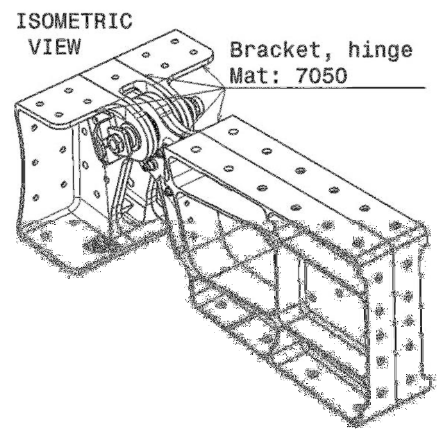

Figure 11 3D representation of a sliding hinge

In order to integrate the steps required for the process the engineering BPM system KE-chain by KE-works was used. Both manual and automated tasks were modelled in the system. The workflow execution enables the automated tasks to automatically trigger tools via a tool server (KE-node by KE-works). For this purpose generic interfaces were made to automatically call Excel and CATIA VBA based tools. KE-chain also provides a product data model which was used to manage the input and output data for each task.
For all geometry related activities, CATIA VBA tools were created, in particular: an import tool to interactively select the relevant geometric components from a native CATIA V5 file; a hinge generator tool to create, size and assemble all hinge components and several geometry analysis tools (e.g. volume measuring, OML intersection constraint checking). Starting CATIA and subsequently running each of these tools with the framework requires no user interaction.
All load sorting and stress analysis activities were implemented in standardized Excel tools. For each standard component a tool was provided capable of computing all relevant margins of safety. Report generation tools were implemented in Python, both generic (excel report based on selected attributes from KE-chain product model) and specific (word stress report).
Fokker has defined many standard parts and materials, but these are often not available in standardized, computer-readable data formats. Therefore standard parts and material data was digitalized into databases that could be imported by KE-chain. Standard CATIA parts (e.g. bolts) were available but often needed to be modified to match with the orientation convention.
The complete toolset (Figure 12) was deployed on the Virtual Laboratory (VLAB) at Fokker, an environment separated from the operational IT environment for R&D purposes. The VLAB LAN consists of a server on which KE-chain and the Python-based tools were deployed and a workstation with a browser

(to access KE-chain), CATIA V5 and MS Office applications. The framework was demonstrated using input data based on a hinge Fokker recently designed.

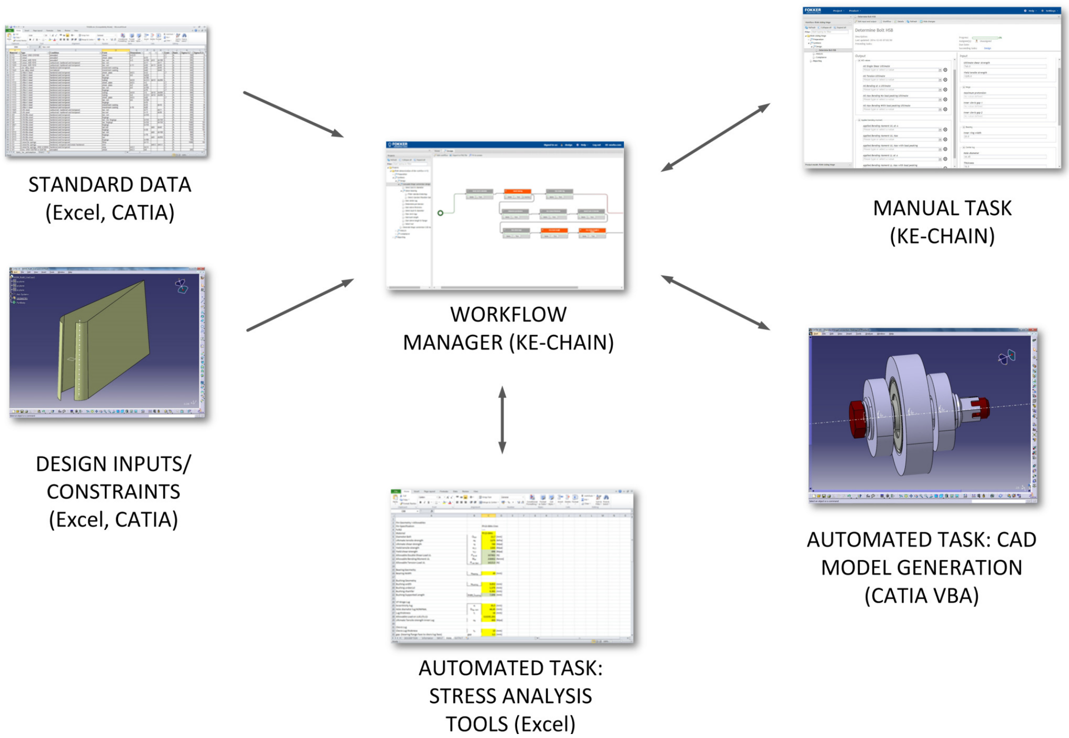

Figure 12 The Rudder in a Month phase 1 main framework components, where the workflow manager orchestrates all data exchange and (automated) task execution

4.3 Phase I evaluation

The first phase showed that a product, which was on first inspection considered to be comparatively simple, actually features more complexity than anticipated. This can be characterized by the large number of parameters in the product model (800 parameters) and tools/scripts created (50 tools). The large number of parameters led to narrowing down the product evaluation scope (e.g. by ignoring tolerance analyses), which means that the case did not cover the detail development process to the desired extent.

The objective of achieving a high level of modularity lead to a large number of small modules, for which interfaces had to be managed. The integration of all modules was done at one level, which, combined with the large number of parameters, increased the complexity of the solution. For the solution to be scalable, some of the integration should be applied in submodules instead of the main product model definition.

Developing the tools for phase I and demonstrating them to Fokker experts provided feedback on the methodologies used in order to obtain a correct procedure. This in fact is an aspect of front loading: formalizing an engineering procedure for automation will trigger questions and can lead to new insights.

4.4 Next phases

This first phase mainly focused on a framework suitable for the analysis of a defined product. Next phases will address cases that include implementing design engineering logic as well and will require the incorporation of search or optimization tools in order to automated iterative design processes. The

product scope will be expanded: concurrently the design of the complete hinges system and the rudder torsion box. The latter has a large overlap with the activities in the TAPAS2 project, albeit for a more detailed scope.

5 Discussion of required elements for implementation of the Fokker vision

As was shown in the 2 case studies there are several technologies that are required to apply the Fokker vision of the future development process. In this section the required elements and their impact on the development process will be discussed.

Standards data management, (simulation) data management. As is shown in the case studies, especially in Rudder in a Month, a lot of data is created in the process of finding the best solution. In order to achieve the required process transparency the simulation, and other data generated in the development process, must be managed in a structured way.

Knowledge management system. As is shown in both case studies knowledge is used extensively, for example in the form of rules used in sizing tools. To be able to manage the knowledge used a well-structured knowledge management system is required.

Design rationale tracking/traceability. Like the knowledge rules discuses in the previous paragraph the design rationale or design logic applied in the development process must be stored and traceable. This makes the automated design process more transparent.

Virtual laboratory. When automating the development process new software and other tools will be introduced regularly. It is impossible to test all this software and tools in an environment that also supports the normal operation of an aerostructures manufacturer. Therefore a separate environment is required where software and tools can be tested rapidly without the danger of disturbing day to day operations of the company. This environment is called the virtual laboratory.

Bridge between structures engineering and software engineering. In the development of tools that fit in the envisaged design system 2 problems are encountered. Firstly tools developed by structural design engineers often are not robust enough or in other words do not meet common software development standards. On the other hand tools developed by software engineers, whilst robust and stable, do not meet the required functionality standards. In order to overcome this the strengths of both sides need to be combined.

Mature KBE system. In the design process geometric manipulations are often required. When used in an optimization loop common CAD systems are often to slow, this was experienced in the TAPAS2 project. Instead KBE systems can be used for geometry generation, these are faster and therefore better fit in an optimization loop. However to Fokker's experience the KBE systems currently marketed are not mature enough. Main issue is the lack of critical mass and the lack of a support base for outsourcing tool development.

Framework integrating processes and tools that fit within a professional environment. As shown in the research projects the design process consists of many tools with a lot of data exchange between them. To run this process, framework management tools are required. However to use these tools in a professional setting security and intellectual property issues need to be addressed.

Mature MDO software and strategies. As was shown in the Rudder in a Month project, optimization is required to find the correct design solution. To be able to do this MDO tools are required that provide the optimization algorithms and fit in a multi tool design environment. Besides tools, optimization strategies are also required to achieve an optimal optimization process.

Culture change of aircraft component engineers. Finally, as was stated before, the most important element of change required for Fokker 's vision to become reality is cultural change. Companies and engineers involved in the design process of aircraft components must realize that design process will fundamentally change in years to come. If they do not adapt to this new reality they will be overtaken by other companies and engineers that are able to do a better job for less money.

6 Conclusions

In this paper the vision of Fokker on a new implementation of the aircraft component design process are presented. This vision is ambitious, but it is a must to remain competitive in the component development business. Realizing this vision will be a challenge that Fokker will not be able to address on its own. In order to achieve the level of automation required partners in the area of software development must be found.

The first steps have been taken to realize Fokker's vision as is shown in the two research projects showcased in this paper. These also show that the vision can be applied to all stages of the design process, from early proposal phase, as shown in the TAPAS2 case, to the detailed development phases as shown in the Rudder in a Month case.

There is still a lot of work to be done to achieve full maturity of the design process automation envisaged. Besides development on the methods and software tools side this will also require a change in the attitude of engineers with respect to design automation. We at Fokker look forward to meeting the challenges ahead and defining the future with a new aircraft component design process.

7 Acknowledgements

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