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PROCESSES AND TOOLS FOR AIRCRAFT HYDRAULIC SYSTEM DESIGN

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Abstract

Using the example of the Hydraulic System, this paper gives an overview of the different kinds of simulations performed during Aircraft System development at Airbus. It is shown that with the application of a newly developed tool (ArOLab) the effort for model development and simulation can be reduced, and more mature results can be achieved already at earlier project phases.

1. HYDRAULIC SYSTEM ON AIRCRAFT – SHORT INTRODUCTION

The hydraulic system is a high power source for many mechanical aircraft systems. Despite the efforts towards a more electrical aircraft, hydraulic power is still essential for services like the actuation of primary and secondary Flight Control surfaces, Landing Gear Extension and Retraction, Braking and some others.

1.1. Hydraulic Power Generation

The pressurization of hydraulic circuits on an aircraft is insured by different independent power sources. On a commercial aircraft, usually these hydraulic power sources can be found:

- Engine Driven Pumps (EDP): They are connected to the engines of the aircraft and are able to deliver hydraulic power as soon as the engines are running.
- Electrical Motor Pumps (EMP): For systems that need hydraulic power on ground, EMPs are installed on the aircraft. They are able to deliver hydraulic power independent from the engines.
- RAM Air Turbine (RAT): For emergency cases a RAT is installed on the aircraft. It can provide hydraulic power in flight for those failure cases where all EDPs are lost.

1.2. Additional Components

Other components that can be found in hydraulic aircraft systems are the following:

- A pressurized reservoir including level indication sensors
- Accumulators
- Manifolds
- Valves for different purposes
- Filters
- Connections for hydraulic ground carts operation
- Heat exchangers
- Pressure and temperature sensors
- Pipes

All of these components have to be taken into account for the simulation activities described hereafter.

2. SYSTEM SIMULATION IN DIFFERENT DEVELOPMENT PHASES

During the development of an Aircraft, the hydraulic system as well goes through different phases. For most of these phases, simulations play a major role. FIGURE 1 shows, which kind of simulation is performed in the different phases of the aircraft development.

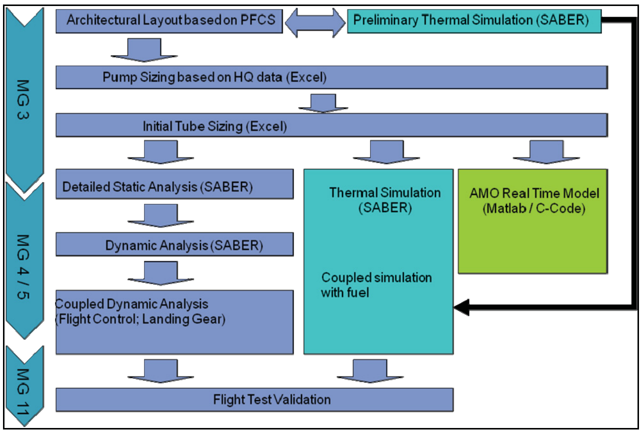

FIGURE 1: The simulation process aligned with the aircraft development

2.1. Pre-Design

In an early stage of the aircraft development, concept studies are performed to find an architecture for the hydraulic system that is optimized for the specific aircraft needs. In these studies, criteria like safety and reliability play a major role, but weight, costs and complexity of the system are taken into account as well. Preliminary sizing of pumps and pipes is another pre-design activity.

2.1.1. Architecture Studies

The system architecture defines the integration of functions and power supply in the aircraft. As Flight Controls is one of the main consumer systems, the architecture of the hydraulic system is mainly determined by the needs and the architecture of the Flight Control system. In addition, safety and reliability aspects play a major role in the definition phase. Following considerations are taken into account in the architecture studies:

- Number of independent hydraulic circuits (for redundancy reasons)
- Number of power sources (pumps) per circuit (for performance and redundancy reasons)
- Availability of power sources (on ground/ in flight)
- Interdependency of power sources
- Assignment of consumer systems to circuits
- Sufficient supply of consumer systems
- Possibility to isolate components/ consumers
- Physical installation/ integration on aircraft
- Pressure level (3000 psi or 5000 psi)

2.1.2. Preliminary Sizing of the System

In order to compare the different architectures and to allow for a final selection, a preliminary system sizing has to be done for all architectures under study. The different aspects that have to be dealt with are the preliminary sizing of the pumps, the physical integration of components on the aircraft and the preliminary sizing of the ducting.

The flow demands of the consumer systems determine the size of the pumps. An important factor is the availability of sufficient hydraulic power in failure cases to supply safety critical systems.

The physical integration of hydraulic system components on the aircraft plays an important role for redundancy aspects and for the control and monitoring concept. Furthermore it has an effect on the size of the hydraulic system (e.g. pipe lengths). Therefore efforts have to be made to optimize the physical integration.

The pipes are sized to provide sufficient differential pressure to the consumer systems and to keep the fluid velocity within certain limits.

With the preliminary sizing, following data are generated based on experience from former aircraft programmes:

- System weight
- System costs
- Amount of fluid in the system
- Power consumption
- Reliability

2.1.3. Concept selection

When the results of the preliminary system sizing are available for all architectures under study, an evaluation is performed with the data mentioned above, taking into account as well aspects like system complexity and operability. Based on this evaluation, the architecture to be used is chosen.

2.1.4. Simulation Tool

Currently the preliminary system sizing is done with a tool based on an *Excel* sheet including some macros. This tool is adequate concerning computation time and the accuracy of data at an initial development phase. Although it has been developed over time, it still shows some significant drawbacks:

- High effort to generate/ change architecture
- No architecture visualization
- No automatic optimisation of system design
- No export interface to subsequent simulation tools

Therefore the need was seen to develop a new pre-design tool that overcomes these weaknesses. A description of this tool can be found in 3.1.

2.2. Detailed System Design

In later phases, when the definition of the aircraft and the required hydraulic power is refined, the system simulations need to be improved as well. This is achieved by a more detailed model of the distribution as well as by the usage of more realistic models of hydraulic components. A transition is made from steady-state simulations to dynamic simulations and to co-simulations with models representing consumer systems. The aim is to size the hydraulic system according to the required performance, but prevent significant oversizing.

2.2.1. Static/ Dynamic Performance Simulations

The first step in the improvement of the simulation models is the implementation of enhanced models of the different system components. These models are delivered by the manufacturers that supply the components. Steady-state simulations are performed with the refined model, using the maximum flows required by the consumers in the different flight scenarios.

In the next step, data are provided by Handling Qualities that allow to calculate the flow demand over time for the different flight scenarios. These data are generated on a flight simulator and contain information on the required position of the Flight Control surfaces over time. Once these data are available, a step is made to dynamic hydraulic simulations as well. The aim of these dynamic simulations is to investigate, if the available differential pressure is sufficient to move the actuators as assumed.

Static and dynamic simulations are performed with *SABER*. The model of the hydraulic distribution system is based on the *Excel* model used in the pre-design phase.

Unfortunately there is no interface available that allows to import model data from the *Excel* model into *SABER*, so the model has to be rebuilt completely.

2.2.2. Coupled Simulations

Scenarios that have proven to be critical in the dynamic simulations are transferred to a dedicated test platform that allows the coupling of the hydraulic model with the models of the consumer systems, pilot inputs and some other simulation models. In these coupled simulations, the interdependency of flow and pressure is taken into account. The results of these simulations are therefore more realistic.

Coupled simulations are performed in a non-constrained time environment. That means that the hydraulic model has to be capable of non-constraint time simulations as well. Today this is realized with *SABER RT*. The *SABER* model used for dynamic simulations can be used for this task with some modifications.

2.2.3. Thermal Layout

The performance of hydraulic fluids is guaranteed in a certain temperature range only. Care has to be taken especially to prevent the fluid from exceeding the highest allowed temperature. Therefore the need for cooling devices is studied already in the early phases of the system development, based on preliminary assumptions.

Once an architecture is selected and the need for cooling is identified, a heat exchanger has to be sized. For this task the complete environmental envelope that is specified for the aircraft is taken into account, and simulations are performed for different flight scenarios. Where heat is transferred to other systems (e.g. to the fuel system), coupled thermal simulations of all involved systems become necessary.

Failures of hydraulic components are as well investigated under thermal aspects to support the classification of failure scenarios.

All thermal simulations concerning the hydraulic system are up to now performed with *SABER*. The models used in these simulations differ regarding their degree of detail, adapted to the different tasks described above. A more detailed description of the thermal simulations performed during hydraulic system development can be found in [2].

2.3. Design of System Monitoring and Control

During normal operation the hydraulic system is a “silent” system. That means that the system will be started up automatically by starting the engines. The EDPs will then provide sufficient hydraulic power to the consumer systems throughout the flight. For consumers requiring hydraulic power on ground the EMPs will be started up automatically upon consumer systems request. Human activity for hydraulic system interaction is required in failure cases and for maintenance only.

The definition and design of the system monitoring and control functions is supported by simulations. Here the aim is to make sure that the system behaves as expected, and that sufficient hydraulic power can be provided to the consumer systems even in failure cases.

Simulations of the monitoring and controls function focus on the system logics implemented in the controller. (I.e. Simulations of the controller hardware are not performed.) During the definition of the system logics, *SIMULINK* is used for simulations. The development of the real software is often done with *SCADE*, therefore this tool is also used for simulations in later phases. FIGURE 2 shows an example of a system logic modelled in *SCADE*.

Another aspect is the development of fault diagnosis systems that allow to identify faulty components faster and with less effort than the troubleshooting and maintenance actions perfomed today. Information from sensors, some of them already being installed on the aircraft, are used for this task. Simulations help to define and optimize this kind of systems. More information on this topic can be found in [3] and [4].

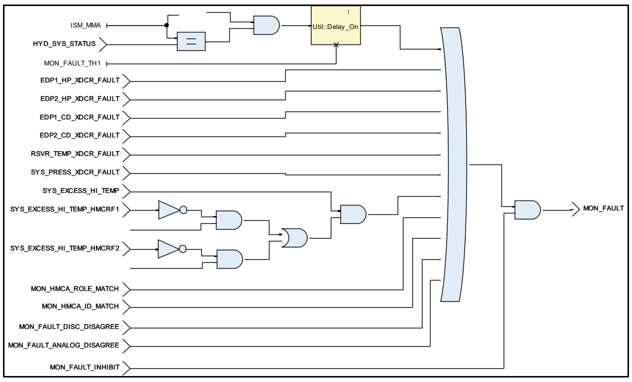

FIGURE 2: Example for the representation of a controller logics in *SCADE*

2.4. ‘Shared Simulation Models’ - Support for Test Benches

To make sure that the different aircraft systems show compliance with given interface requirements, there is a process in place that allows the virtual integration of system models on aircraft level from a very early aircraft development phase on. In the associated procedure the general process to develop ‘Shared Simulation Models’ is described. This includes all rules and requirements for ‘Shared Simulation Models’. They have to be platform-independent and real-time capable, so that they can be run on simulation platforms that are connected to real aircraft controllers.

This process is mainly focused on the integration of the different system controllers and computers. The aim is to make sure that the information exchange between the controllers of the different aircraft systems is harmonized and the interfaces are consistent. Therefore an additional controller model has to be developed according to the rules given in the procedure.

To make adequate use of the controller model, a 'Shared Simulation Model' of the physical system is needed as well to generate meaningful responses on controller actions. This makes it necessary to develop an additional model of the hydraulic system and maintain it throughout the whole development cycle. As for the controller model, the requirements for this kind of 'Shared Simulation Model' are:

- The interfaces have to be well described and as similar to real aircraft interfaces as possible
- The model has to be generic and not suited to one computer environment only
- The model must be real-time capable

The procedure asks for 'Shared Simulation Models' in *C-code*, but supporting tools are available that allow the translation of *SIMULINK* models according to the rules given in the procedure.

2.5. Tendency towards Virtual Testing

Testing is an important means to show that the system works as expected.
Lab tests are performed on component level, and the complete hydraulic system is tested in a lab as well before being installed on an aircraft. Afterwards, Flight test campaigns are carried out.

In the last years, the approach has been made to reduce the amount of testing and replace it by virtual testing, i.e. by simulation. This approach again puts some new demands on simulation models. Simulation has to be validated with real test data. That means that simulations have to be able to reproduce data that have been recorded during tests with a high accuracy.

Studies have been started to select a simulation tool that is suitable to replace some of the lab tests, and beneath the tools already in use (*SIMULINK*, *SABER*), *AmeSIM* has proven to be promising. A final decision on the tool to be used for coming projects, however, is still outstanding.

2.6. Support of In-Service activities

Some of the test benches, real or virtual, are kept in operation throughout the whole service life of the aircraft. They are used for trouble shooting and for testing of modifications to be introduced on the aircraft.

That means, that some of the simulation models, especially the 'Shared Simulation Models', have to be kept and maintained as well.

3. INTEGRATED TOOL CHAIN

As described above, simulations are performed on many occasions and for many different purposes during the development and lifetime of an aircraft. Up to now, different tools have been used for the different purposes, and models had to be built in each of these tools individually. There was no automatic transfer of architecture or model data from one tool to another. This approach is time-consuming, and much work has to be done to assure the consistency of models in different tools. In addition, model configuration control has to be performed for each of the tools independently.

In order to reduce the effort for model generation and data management a project was started to optimize the complete simulation process and simplify tasks where possible. In this project, the current process was analyzed concerning weaknesses and strengths. Ideas for improvement were collected, and a sketch of the future process was drawn (see FIGURE 3).

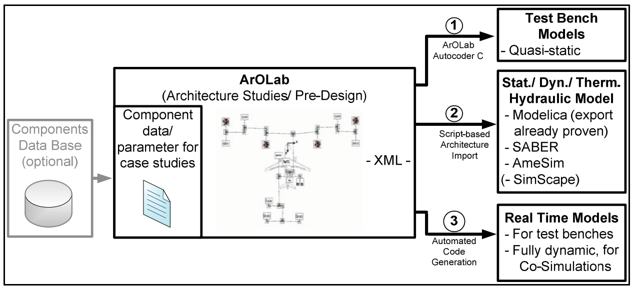

FIGURE 3: Sketch of the planned simulation process

3.1. Architecture studies and preliminary sizing with ArOLab

One weak point identified in the analysis was that the tools used in the very early phase of the system development (architecture selection, preliminary sizing) are rather complex and not very user-friendly. The main drawbacks are:

- Due to the complexity of the underlying structure, much effort is needed to set up or change a model.
- The chosen architecture is not visualized.
- There is no automated system optimization available.

To overcome these weaknesses, the development of a new tool, ArOLab, was started. A detailed description of ArOLab can be found in [1], but some of the major benefits are mentioned here as well.

ArOLab provides a Graphical User Interface to build and visualize the model (see FIGURE 4). Components can be selected from a library and integrated into the model via drag and drop. The underlying parameters and information on the modeling of the components can be seen and adapted in the library, and important parameters can be shown in the graphical system representation. Furthermore the implementation of an automated system optimization with regards to parameters like system weight, costs or hydraulic performance is planned for the near future.

As the effort for model generation is considerably reduced with ArOLab, it is possible to compare more different architectures in the beginning of a project. Together with the optimization function this helps to achieve more mature results already in an early project phase.

ArOLab performs steady-state calculations only and can therefore not be used for the simulation tasks as described in chapters 2.2 and 2.4.

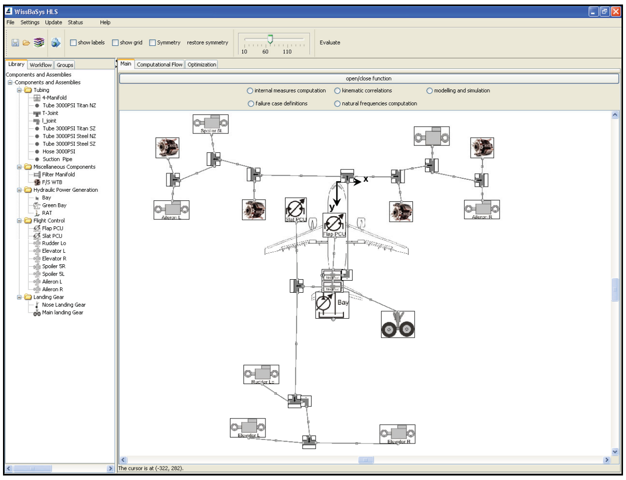

FIGURE 4: Graphical User Interface of the ArOLab tool

3.2. Master Model and export to other tools

Another important improvement of ArOLab, however, is the possibility to export either the complete model or architecture and model data. With this feature it is possible to automatically generate models in the subsequent tool chain with the following advantages:

- As the system representation chosen with ArOLab is rather mature, the need for later changes is unlikely.
- The workload for model generation in the different tools is drastically reduced.
- The consistency of the models used for the different tasks is guaranteed, as all models are derived from one 'master model'.
- This makes version control and management easier.

The export function is still under development. The export capabilities to *Modelica* have already been proven. The final export function depends on the results of the tool selection studies that are still ongoing.

4. CONCLUSION

A variety of different simulation tasks need to be done during the design of hydraulic systems for commercial aircraft. Currently the simulations performed in the various stages of the development process make use of different simulation tools. Although results coming from this process are mature, potential for improvement has been identified concerning the efforts spent in the simulation process.

With the introduction of a new pre-design tool and the harmonization of the following tool chain it is foreseen to make the complete simulation process more efficient.

REFERENCES

[1] DUNKER, C.; THIELECKE, F.; HOMANN, T.: *New computer-aided methods for preliminary architecting and sizing of Aircraft hydraulic systems*, Proceedings of DLRK 2011

[2] BEHR, R.; BROWN, J.; BAUMBACH, V.: *Aircraft thermal system simulation – Hydraulic and fuel*, Proceedings of the 3rd International Workshop on Aircraft System Technologies, ed. by F. Thielecke, O.V. Estorf, Hamburg 2011, pp. 83-92

[3] POOLE, K.; ARRIOLA GUTTIERREZ, D. A.; THIELECKE, F.: *Model-based Development of Diagnosis Rules for Aircraft Hydraulic Power Distributions Systems*, Proceedings of the 3rd International Workshop on Aircraft System Technologies, ed. by F. Thielecke, O.V. Estorf, Hamburg 2011, pp. 92-103

[4] POOLE, K.; RAETH, M.; THIELECKE, F.; MÄDIGER, C.: *Leakage Diagnosis for Electric Motor Pumps in Aircraft Hydraulic Systems*, Proceedings of DLRK 2011