

Modeling Test Rigs for Airplane High-Lift Systems by Data-Based Models

Airbus and Ansys are developing data-based models for dynamic systems to be used in real-time tests. The aim is a decisive contribution to the digitization of work processes and an increasing efficiency in development and testing.

/ Aircraft High-Lift System

The High-Lift System (HLS) of an aircraft has the task of generating additional lift in various flight phases. In aircraft development, on the one hand, it has to be designed for optimum take-off and landing behavior, and on the other hand it has to offer the lowest possible air resistance during the flight phase. In addition to aerodynamic efficiency and flight performance, functional safety is a key development criterion.

Figure 1 shows the control of the leading edge panels (slats) and trailing edge panels (flaps). The commanded position is transmitted from the cockpit via the Slat Flap Control Computers to the drive units of the transmission system for the slats and for the flaps. This means that the flaps on both wings are usually moved symmetrically.

/ High-Lift Test Center in Bremen

Since the beginning of the A380 high lift testing in 2001, the Airbus High-Lift Test Center is based in Bremen. In a 10.000 sqm hall, high lift systems for all Airbus A/C models are tested. The main activities of the High-Lift Test Center in Bremen are the integration of the HLS on test rigs, the implementation of the HLS certification test program and the execution and analysis of the necessary tests for release of the HLS for the "First Flight" and for "Entry into Service."

Since 2015, Ansys Dynardo, the Airbus High-Lift Test Center and its partners Airbus Group Innovations Hamburg, P3 Group Hamburg and MSC Software Munich have been running research projects to introduce accurate and fast data-based models into virtual test environments. The current project AGILE-VT / ViSA, funded by the Federal Ministry for Economic Affairs and Energy (BMWi) under call no. Lufo 5.3, aims at the advancement of such models for dynamic, interactive application within a real-time environment.

/ Test Methods

There are different methods in place for the testing of HLS.

1. Physical Benches for Testing of System Components

As shown in Figure 2, physical benches are used for the certification of high-lift systems. Original components are installed in aircraft-type specific test rigs. The physical benches are also required for later verification of model extensions. To comply with the obligation to provide evidence to the authorities, these tests have to demonstrate that all system requirements have been met. For this purpose an intensive test campaign as part of the type certification is necessary.



Figure 1. Principle structure of the High-Lift System (HLS).



Figure 2. Test rig of the A380. In the front, drive systems and load cylinders to simulate the air load.

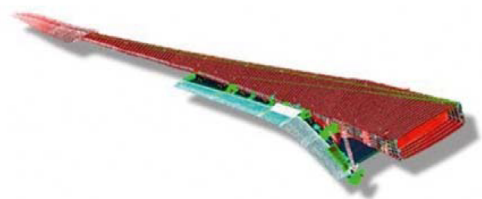


Figure 3. Model of the A350 wing, simulation of wing bending.

The advantages of physical tests are, on the one hand, that the test setup is a representative equivalent of the aircraft and the results obtained are accepted by the authorities. On the other hand, each aircraft-type requires its own highly complex test rig, whose installation and maintenance is very cost and time intensive. Original components must be used which may not be available during the early development phase. The range of application of physical tests is limited by the mechanical construction; changes of the test rig are only possible by complex reconstructions.

2. Functional Models for Testing the Function and Logic of the Control Computers

Simulators are used to test the HLS control computers in a simulated aircraft environment. Original parts are simulated by software modules. Simplified models can be used for the purely functional simulation, hence detailed modeling of physical behavior must not be considered. This kind of test enables a high degree of automatization and real-time capability, which corresponds to a typical clock cycle of 2ms. Functional or logical tests are conducted that way, e.g. the checking of threshold values, time spans for certain processes, etc.

3. Virtual Tests Using Detailed Simulation Models

Virtual tests are used, for example, for experiments which cannot be performed on the physical bench. Figure 3 shows an example of a simulation with wing bending (large deformations). Modification of test properties such as stiffness, friction or damping can be easily implemented without rebuilding the virtual test rig. In order to simulate entire motion sequences, the simulation models include both the respective aircraft components and the test rig itself (see Title Image).

Disadvantages of virtual tests are high computing times, which, on the one hand affect the waiting times and on the other hand prevent the real-time capability. A physical reference system is always necessary to verify or optimize the accuracy of the virtual model.

/ Data-Based Models

In this context, Data-Based Models (DBM) are purely mathematical models for dynamic system reactions, without physical modeling. They thus differ from so-called Reduced Order Models on a physical basis. The DBM are exercised on the basis of given data. In the ViSA project, no real experiments are used for the training, but virtual experiments with a precise simulation of the High-Lift system. This allows a large amount of data for the training and the targeted generation of additional support points in areas where the accuracy must be increased.

Of course, the detailed models must also be able to reproduce the experiment exactly in order to provide high-quality training data for the DBM. It is possible to use parameter identification methods to adapt the detailed models to experimental data so that they deliver the most realistic results possible. However, they are usually much too complex to interact with a test rig in real time. DBM are also advantageous for the investigation of parameter uncertainties or tolerances within the framework of a variance-based robustness analysis. This allows the influences of tolerances or parameters which are difficult to measure (such as damping or friction) on the system behavior to be determined quickly, thus enabling more robust and mature systems to be developed.

A first concept of the DBM was developed in the context of a preceding project [1], [2]. These developments led to the Field Metamodel of Optimal Prognosis (F-MOP), a module of Statistics on Structures (SoS), which can be easily used in optiSLang via the MOP node.

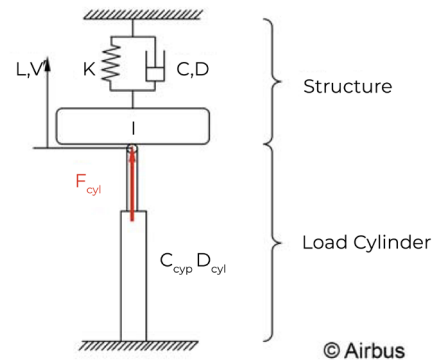


Figure 4. Demonstration model; component "Structure" is represented by a DBM.

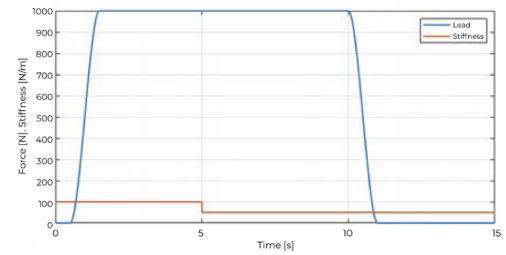


Figure 5. Transient load on the cylinder and stiffness of the single mass oscillator.

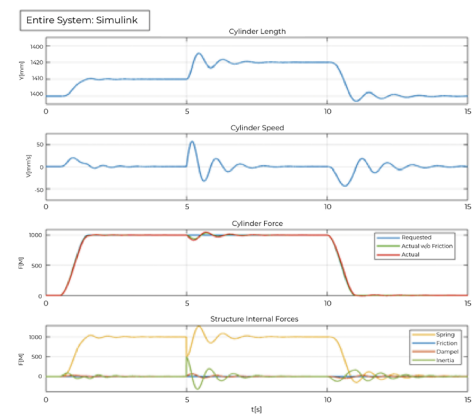


Figure 6. Reference solution for the complete system consisting of load cylinder.

The method of the model approach is to generate a Design of Experiments (DoE) out of the input parameters and to calculate the time series of the responses of the simulation model. The loads of the simulation model are given by the considered virtual experiment. SoS develops the signals by Karhunen-Loève decomposition into a series of invariant form functions scaled by variable amplitudes. The well-known MOP algorithm generates metamodels of the amplitudes depending on the input parameters. The MOP solver, which in turn calls a SoS library, can be used to generate the corresponding signals for new parameter sets within one step. The limitation of this approach, however, is the fixation of the signals over the entire duration of the process. In this sense, the model is static or time-invariant.

In order to integrate the DBM into a system as a component, e.g. to replace part of a test rig as a software-in-the-loop, it must be able to react to changing loads. In addition, the model must also react dynamically to changing parameters for simulating experiments such as artificial actuator failure or wing tip break.

The further development to a dynamic DBM requires a time integration. In the first step, the DBM is again trained on the basis of the transient time series resulting from a DoE of the parameters. Here, unit pulse loads are applied to the simulation model. In a second step, the displacements in the time domain are determined by numerical solution of the Duhamel-Integral. The approach bases on the assumption of any load time series as a chain of impulses. The time series of the displacements result approximately from summation of the impulse responses, starting with the current time step and scaled by the current external load [3]. This solution is valid only to linear, time-invariant systems with one degree of freedom. If the system parameters change, the system is no longer in balance. Even though, it is easy to determine the disequilibrium by summing the internal and external forces and to minimize it by simple iteration within the time steps. This allows the dynamic DBM to respond not only to changing loads, but even more to weak non-linearity. The formulation of this balance correction requires an insight into the physics of the system, so it is no longer a purely mathematical model. However, it should be emphasized that this error correction does not consist of a comparison with a reference solution, but is only generated from information provided by the DBM itself. In literature further Duhamel solutions for other differential equations can be found.

During application, usually, one has to deal with multiple degree freedom systems. If there are few excitation points and also the structural responses are to be evaluated at few points, the Duhamel approach can still be used. It can be shown that coupling terms can be considered as single degree of freedom systems, too. The solutions for the respective degree of freedom and coupling effects can be superposed. So, one has to create a corresponding number of DBMs for all combinations of excitation and evaluation points.

/ Demonstration Example

The effectiveness of the DBM approach will be illustrated using a simple test example. A hydraulic load cylinder with a connected single mass oscillator (“Structure”) is considered (see Figure 4). A force requirement is modified by the cylinder due to internal friction and damping as well as the adiabatic effect and passed on to the single mass oscillator. The feedback of the reaction of the single mass oscillator to the cylinder is affected by displacement and velocity.

The single-mass oscillator is simulated by a DBM that interacts with the load cylinder. For the training of the DBM, virtual experiments with Simulink were performed, varying the system parameters stiffness K , Coulomb’s friction C , viscous damping D and mass inertial. As a test case, a load is applied as a ramp between 0.5 seconds and 1.5 seconds and removed between 10 seconds and 11 seconds. In addition, there is a 50% jump in stiffness at 5 seconds (see Figure 5).

The entire system was simulated with Simulink as a reference. To use the DBM, Dynardo’s F(ield)-MOP-solver library is linked to Matlab and the interaction between load cylinder and DBM is simulated there. Figures 6 and 7 show the excellent agreement between the reference solution and the dynamic DBM.

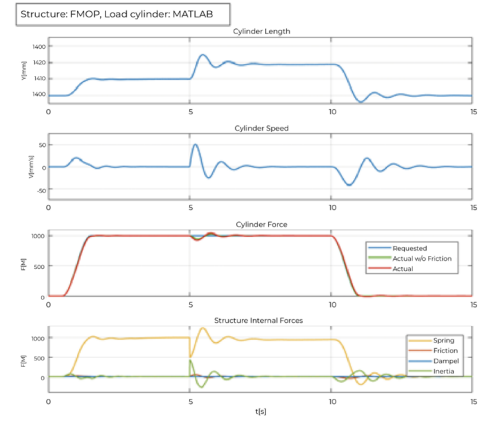


Figure 7. Simulation of the single mass oscillator as dynamic DBM.

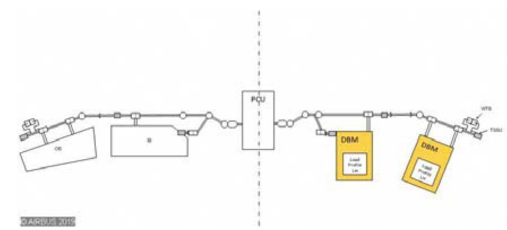


Figure 8. Use of DBM at the HL test rig.

/ Conclusions and Perspectives

Data-based models are able to simulate dynamic structures fast and accurately. In addition to the use of DBM in interaction and thus as an extension of physical or functional experiments, they also enable rapid uncertainty analyses to prove the expected function of components. The models presented here are mathematical in nature, in contrast to e.g. Reduced Order Models. Through the extension by a time integration, the simulation of dynamic structures is possible. The transfer to other physical phenomena, e.g. temperature flow in motors and control units, is supposed to be possible.

In a previous project, data-based models were developed, which were able to simulate the detailed physical behavior of a HLS transmission in connection with model uncertainties (e.g. friction, damping) in the virtual test. The execution speed could be increased by DBM up to real-time, i.e. 500 cycles per second, while maintaining accuracy in comparison with physical tests.

The current project aims at replacement of a physical component at the test rig by a DBM. The behavior of structural components such as landing flaps is to be simulated using DBM on the test rig, Figure 8. Structural components are required for testing system components. They represent the passive aircraft environment controlled by the system components.

By using DBM in aircraft development, experiments can be carried out much faster and more flexibly. The construction of the test rig is simplified by simulated structural components and is more flexible for different aircraft types by simply modifying the DBM. Both rig-like and aircraft-like tests are available. The former also serves the planning and validation of physical experiments. Aircraft-like tests can be performed early in the development phase even before original physical components are available. This will significantly reduce development time and offer the opportunity to increase the product maturity.

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