

PARAMETRIC MODELLING AND EXPERIMENTAL VALIDATION OF MULTI BODY SIMULATIONS OF ELASTIC FLAP SYSTEMS IN TRANSPORT AIRCRAFT

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Abstract

In the development of high lift systems, failure dynamics and associated loads and deformations on structural parts are of specific interest for design and dimensioning the structure. As the dynamics of aerodynamically high loaded, flexible structures in failure cases are very complex and hardly predictable, there is a strong motivation for prediction of dynamic loads by modelling and simulation of the affected structures. The objectives of this work are the estimation of dynamic effects in early design phases as well as the support and simplification of complex tests needed for certification in the end of the development cycle.

With this objective, Hamburg University of Technology, Institute of Aircraft Systems Engineering, has developed an environment for simulating highly dynamic operation and failure cases with a model of the complete structure of the flap system. This work is part of the European Union's research project VIVACE (Value Improvement by a Virtual Aeronautical Collaborative Enterprise). The model includes all structural flap segments, their support mechanisms and the system for application of air loads, as built up on a certification test rig. The modelling strategy is based on multi body dynamics and finite element analysis, such that the system representation is composed of rigid and flexible body models.

For model validation test results from a certification test were used. It became obvious that certain areas and structural parts of the system had to be modelled with a high degree of detail in order to consider all physical effects that influence the system dynamics. Comparison of simulation and test results show a high correlation if adequate model structures are analysed.

1 INTRODUCTION

Large transport aircraft are usually equipped with high lift systems, which enable them to reduce the speed needed for starting and landing. Consequently, a shorter runway is needed, the tyres are less stressed, and the airport approach flight before landing can be steeper. The reduction of the speed necessary for maintaining the lift force is possible by increasing the effective wing area and the wing camber, thus

increasing the overall lift capability of the wing.

This is reached by providing the leading and the trailing edge of a wing with slats and flaps respectively, which in combination with their mechanisms form the structural part of the high lift system. While the extension of slats permits a higher angle of attack of the air stream before stalling, the flaps extension raises the overall lift for any angle of attack by increasing wing camber and effective wing area. The flap system of the aircraft considered here is for each wing composed of three flap segments, figure 1. A branched system of shafts and gears is transmitting mechanical energy from hydraulic motors at the aircraft fuselage to the track and drive stations, whereas two track stations are located below one flap segment.

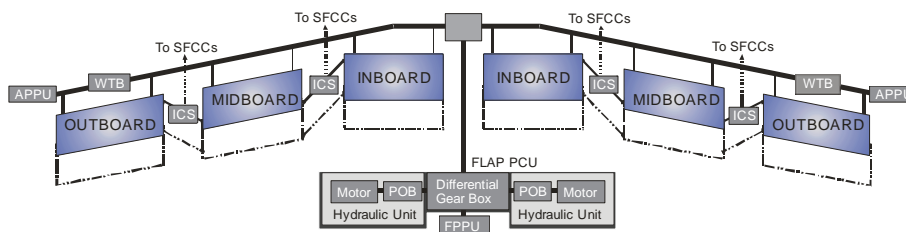


Figure 1: Trailing edge flaps and flap drive system.

While being extended, the flaps have to be precisely positioned and oriented on spatial paths in order to meet aerodynamic requirements and to avoid collisions with adjacent wing structure. This motion is realized by complex mechanisms of the track stations. Besides exact positioning, these mechanisms must fulfil high requirements to stability and safety.

All track stations except the most inner station are built in the same manner, as shown in figure 2: The main load of the flap is supported by the carriage which can move translationally along the trackbeam. The trackbeam is connected to the wing structure, into which it conducts all external loads. A rear link and a rotary actuator are mounted to the trackbeam. While the rear link additionally supports the flap besides the carriage, the task of the rotary actuator is to move and to position the flap via the drive strut.

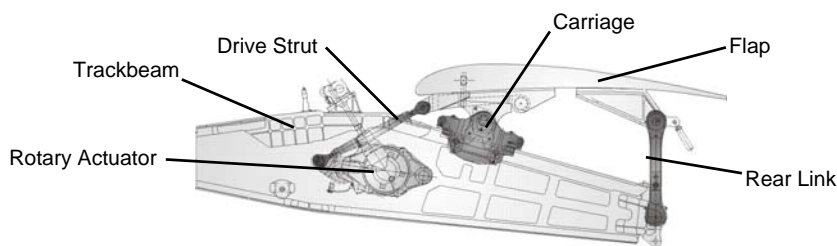


Figure 2: Design of a track station.

Especially for flaps, a structural damage in a part of the flap mechanism or in the drive system can result in a hazardous failure condition. In order to ensure a safe continuation of flight, the high lift system is equipped by various safety devices which have to be tested and certified. For this reason, test rigs are built which contain all components of the high lift system. For investigation of structural loads in failure cases it is even necessary to merge the flap bodies and their mechanisms to the test

rig. The air loads are then imposed directly on the flaps by force actuators. These test set up and procedures are particularly in case of large aircraft projects very time and cost consuming.

1.1 Dynamic Failure Cases in Flap Systems

The flap interconnection strut (ICS), shown in figure 1, is a safety device which is intended to work in case of a failure in the drive strut or the rotary actuator of a track station. After a failure in the drive strut, one end of a flap is no more fixed and can move along a path determined by the remaining parts of the track station. High external air loads accelerate the free end of a flap, but this acceleration occurs for a very short period, since the ICS gets active and establishes a mechanical connection between the flaps. Figure 3 describes this circumstance for a failure in the outer track of the inboard flap. The free end of the inboard flap is here fixed by the adjacent track station via the ICS.

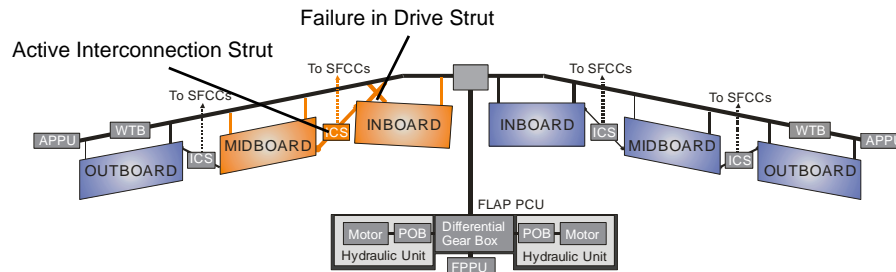


Figure 3: Active interconnection strut after mechanical failure.

Evidently, forces and deformations are much higher in this case than in regular operating conditions. The system behaviour in this failure case can be described by two static states and a highly dynamic period in between, figure 4. The high frequency oscillation is caused by the drive strut rupture and the ensuing activation of the ICS, acting like an impulse that spreads over the system. Due to the damping of the structure and of the interconnection strut, this oscillation is damped within a few seconds such that the complete system reaches a different static state.

The ICS is a safety device that is to be certified by such a complex test as described above. The simplification or substitution of such complex tests offers high potential for savings in development effort for aircraft industry, but also puts high requirements on a model and a simulation in terms of accuracy, reliability, validation and traceability.

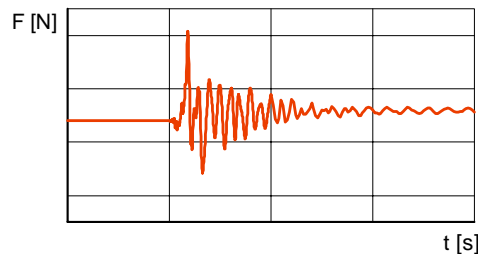


Figure 4: System dynamics in case of a drive strut rupture.

1.2 Project Aim and Project Structure

Above mentioned simplification of complex certification tests is the primary aim of the project work. It is envisaged to use smaller test rigs and subcomponent tests and to take advantage of a system simulation validated by subcomponent tests for certification. Another project aim is the integration of dynamic system simulations in earlier development phases in order to predict dynamic failure loads and deformations and use the results for design specification.

The first part of the project structure is the development of a simulation model suitable to meet the requirements. A multi body simulation with integrated finite element structural models was chosen for simulation, as mentioned in the next section of this paper. First simulation runs on this simulation model were performed before tests were carried out and prognoses of first test runs were accomplished.

Secondly, after various test results were available, comparisons of test and simulation results could be used for model refinement and model validation, [4]. Parts of the model were identified that had to be modelled with a high level of detail in order to include all physical effects that govern the real system dynamics. In section 4 of this paper results for validation will be presented.

The third phase of the project deals with the extension of the model to in-flight dynamics. On basis of a simulation model validated by a ground test, present modelling methods are to be extended by more realistic boundary conditions. This refers to an elastic and deformable wing and a description of external loads that accurately approximates air loads occurring in flight.

2 SIMULATION MODEL DEVELOPMENT

Simulation requirements can be met by a multi body simulation (MBS) like MSC.Adams: A MBS describes systems of rigid bodies with a quite high accuracy and simple equation systems. In comparison to the finite element theory, it is able to describe complex systems in their complete operating range and to map highly dynamic transients in the system states. It is thus able to predict peak loads and deformations that occur after a structural failure in the flap system.

The majority of the flap system is modelled by rigid bodies. However, for systems with coupled elastic elements like the flap structure, the simulation results would not match reality if the structural elasticity were not adequately represented. Although the elastic deformations of the structure are relatively small in comparison to the dimensions of the flap segment, their influence on the static states and especially on the dynamics of failure cases can be significant. For this reason, the elasticity of various parts has to be taken into consideration.

By usage of flexible bodies in MSC.Adams the model accuracy can be significantly raised, [2]. MSC.Adams uses a description of modes and mode shapes of a finite element body and connects the formulation of equations of motion and kinematics to the modal formulation of the deformation of an elastic body. The modes and mode shapes of an elastic body are calculated off-line by the finite element analysis software MSC.Nastran and are then imported into the multi body simulation by a modal neutral file, figure 5. In order to reduce the dimension of the finite

element formulation of a flexible body, substructuring and component mode synthesis techniques are used, [1,5,6]. The basis of modes that is calculated only concerns those nodes of a finite element body that are subjected to forces or joints in the multi body simulation. This reduces the amount of computer time needed. Concerning the flap structure, especially the flap segments and the trackbeams deform significantly and have to be represented by flexible bodies. Beyond the integration of simple finite element models into the MBS, methods were developed that allow the inclusion of finely meshed flaps and trackbeams of high complexity without loss of simulation performance, see [3].

In the validation phase of this new model, [4], different model alternatives and design parameters had to be studied, evaluated and used for model validation. Particularly in this phase, it is helpful to have the opportunity to easily change model parameters as well as the structure of the model. For this purpose and for reasons of being able to use the results of this project for further aircraft developments, a model file creation tool was developed which automatically creates a model code for the multi body model. The structure and benefits of this tool will be described in the following section.

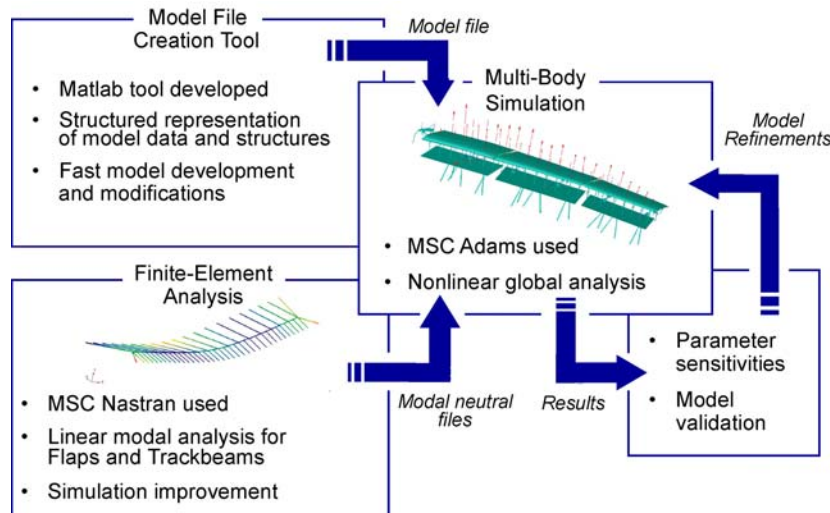


Figure 5: Structure of modelling and simulation.

3 MODEL FILE CREATION TOOL

The effort for model creation and model modification can be very time consuming and error prone. For this reason a model file creation tool was developed. This tool is written in Matlab and offers a high efficiency in creating and modifying models as well as in their documentation.

The model file creation tool consists of three types of files: Via a main file, data files for subsystems (figure 6) are loaded subsequently and for each data file, a subsystem topology template is executed. Each data file contains all relevant design data for one distinct subsystem, while a topology template contains general definitions of parts, constraints and forces. Each definition of a part, constraint or

force contains flags that determine the type of model element. This information is passed to general model element files, which contain complete definitions for a wide variety of model elements and modeling alternatives.

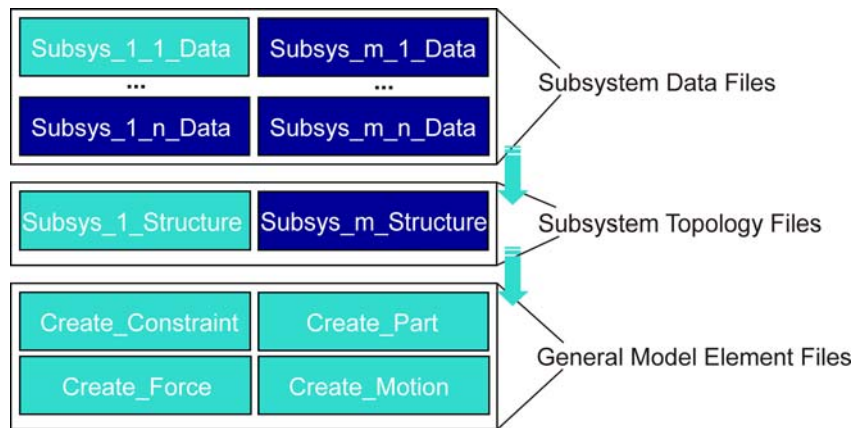


Figure 6: Structure of model file creation tool.

This structure of data files and topology files permits a fast and parameterized model file creation. The resulting model is parameterized in design parameters as well as in spatial hard points, to whose locations the modelled mechanism is adjusting. In addition, any parameter can be declared as a design variable, such that the model can be used in MSC.Adams/Insight for parameter studies.

Particularly in case of present high requirements to model validity and traceability, it is important to have the opportunity of easily documenting the parameters and the structure of the model. The data files of this tool offer a clear, structured and compact overview on all parameters including references and a history of parameters. This documentation ensures traceability and a clear outline.

Furthermore, the existent model contains model elements that are not part of common libraries, so that the physical model behaviour must partly be described by functional dependencies. The correctness of all user-defined model elements must furthermore be verified. These user-defined model elements are part of the general model element files, they are validated and can be reused if required.

Another advantage of general model element files is the flexibility in level of detail this tool offers. This means that with one persistent set of parameters and slight modification of the relevant topology files, models of higher level of detail can be generated. This refers to bodies of the multi body model, which can be modelled by stiff or elastic bodies, and to model constraints, which can be ideal, linear elastic, nonlinear elastic, involving friction or backlash. This procedure is advantageous in two aspects: On one hand a flexibility offers the opportunity to build simple models, test these models for correctness and subsequently refine the models where required. This commonly known “crawl-walk-run”-approach is essential for building correct models of high complexity. On the other hand, a flexibility in level of detail offers the opportunity to create models for supporting early design phases where few parameters are known and the level of detail required is less.

The advantage in using general model element files can be demonstrated by the constraint of the carriage roller, figure 7. This constraint consists of numerous rollers

connected to the carriages, such that the carriage can move translationally along the track. Ideally, this constraint is a translational joint, only allowing relative motion in one direction. In reality, friction, backlash and a small motion in constrained direction exist in this constraint, which can have a high impact on simulation results. The tool offers a large variety in alternatives for modelling this constraint by ideal or more complex, realistic elements by changing flags determining the type of constraint.

The information stored in a topology file is the names of the parts the constraint connects, its location and orientation and if required information about friction coefficients, backlash, linear or nonlinear elasticity. This information is passed to the general model element file "Create_Constraint", which generates all necessary model code for markers, functions, measurements, and structurally composes names of all elements. In conclusion, the effort for creating templates is minimized by application of this tool. This approach is also chosen in case of parts modelling: In this case, there exist various alternatives for modelling the mass and inertia of a part as well as for modelling rigid bodies or flexible bodies.



Figure 7: Carriage roller constraint.

4 MODEL VALIDATION

For validation purposes, the model is adapted to a complex test rig that was installed for flap system certification.

For validation purposes the flexible multi body model is adapted to the test set up displayed in figure 8: This test rig is used for certification tests of the flap system. It is composed of the original flap structure and drive system of the left hand wing. In order to simulate air loads, a hydro-pneumatic load simulation system is installed below the flaps. This system consists of three hydraulically driven hexapods which position a moveable steel frame below the flaps. Between this steel frame and the lower surface of each flap, numerous pneumatic cylinders are installed which exert forces to the flaps. These forces variable in magnitude and direction simulate the real air loads occurring in flight.

The multi body model of the air load system includes all parts installed at the test rig, whereas the length of each hydraulic cylinder and the force of each pneumatic cylinder are input quantities which can be imported into the model using the same data format as the input files that determine the set values of the test rig controller. Consequently, all test cases that are executed at the test rig can be mapped by the model.



Figure 8: Test rig for flap certification and model validation.

The complete parameterization of the model made it possible to test various model structures and to determine regions of the model that govern the model behaviour. The following figures show that it is possible to map the system behaviour with high quality. In this paper, exemplary validation results will be shown that refer to two distinct test cases: The first validation case presented here examines the simulation accuracy for a drive strut rupture under high external loads. This test case has already been presented in section 1 of this paper. It is the test that results in the highest structural dynamic loads the system has to withstand. The second validation case is related to a static test, during which external loads are applied to the flap surfaces while the flaps are deployed slowly until the maximum flap angle is obtained.

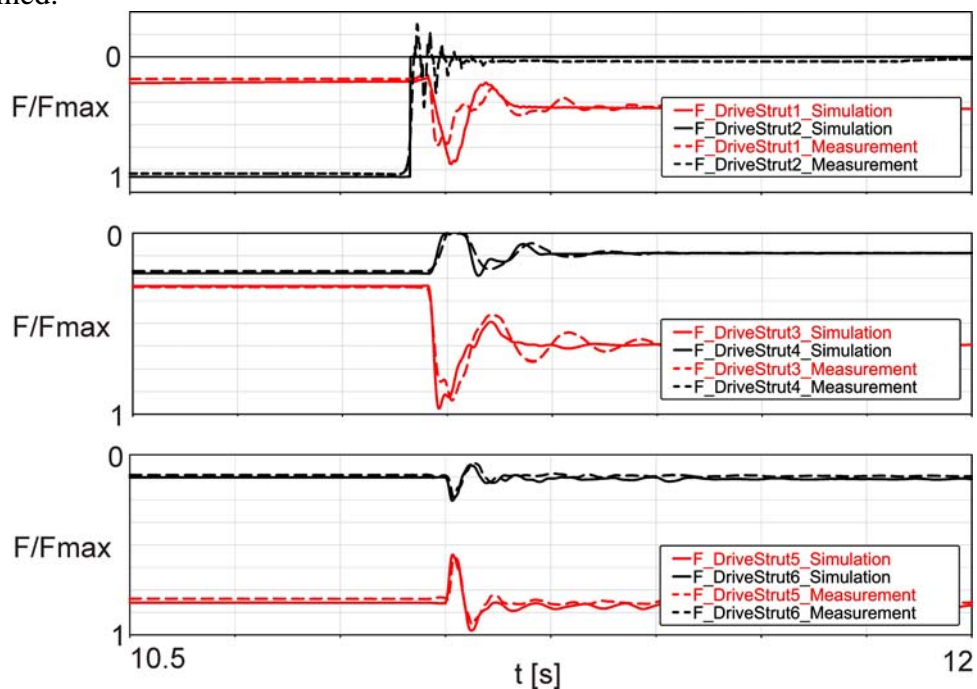


Figure 9: Validation results for drive strut rupture.

Figure 9 shows the test and simulation results for the forces occurring in the drive struts in case of the rupture test validation. Test and simulation results correlate very well in static loads as well as in dynamic peak loads and damping characteristics, relative errors in static and dynamic loads hardly exceed 5 percent.

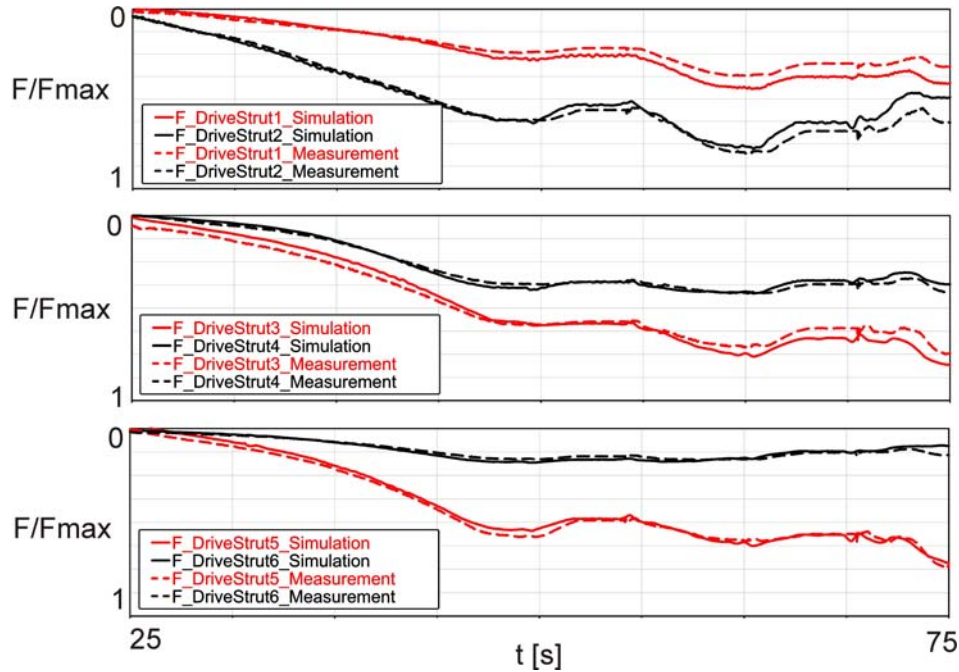


Figure 10: Validation results of static flaps extension.

Figure 10 presents validation results for a static test, during which the flaps are driven from retracted (cruise flight) position to extended (landing) position. This test indicates if the model maps the real system in its complete operating range, which puts requirements on the model that are different from those for mapping the dynamic test. Results show that for the static test the relative errors are slightly higher than for the dynamic test, especially in the end of the simulation for high flap angles. It is supposed that several rubber sealings in the region between the flaps, which are not part of the model, affect the system behaviour for this test case. Further tests with dismantled sealings should be carried out for model validation.

5 CONCLUSION

This paper presents a new methodology for efficient multi body modeling and simulation of flap systems, which is used to determine dynamic effects that occur in operating cases and especially in several failure cases. This methodology can be used in aircraft development process of high lift systems for early estimation of dynamic loads and effects as well as for simplification of complex certification tests.

The model that is presented consists of rigid bodies and of flexible bodies that result from a modal analysis of finite element models of arbitrary size. These finite element models are integrated into the multi body simulation in a runtime efficient way. For efficient, traceable and reusable model file creation for future aircraft

projects, a tool was developed that uses a structure of data files, model topology templates and general model element files. This approach permits a stepwise refinement in level of detail by usage of a persistent set of data. Furthermore the tool contains verified definitions for complex submodels that can be reused if required.

Comparisons of test and simulation runs showed that this approach is suitable for accurate determination of the system dynamics.

Further developments will focus on the extension of the model by effects that occur in flight. These effects are wing deformation and a distributed aerodynamic pressure load that is dependent on the deformation of the flaps themselves and thus the resulting gap and overlap of the slotted high lift devices.

6 REFERENCES

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