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USE OF MULTI-BODY SIMULATION FOR THE CALCULATION OF DYNAMIC LOADS AND ACCELERATIONS ON A380 FLAP MECHANISMS DUE TO OPERATIONAL LOAD CASES

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Summary

As a result of the development of larger and more efficient aircrafts like the A380 and the A350XWB the need for optimization of high-lift systems increases significantly. In contrast to this, the increasingly shorter development and testing time makes it necessary to optimize the design process in prediction accuracy due to static and dynamic loads. Generally, the design and dimensioning of high-lift systems are mainly affected by failure cases. Albeit, operational load cases, like a landing gear impact, can have dimensioning effect, too. Hence, these effects have to be investigated and considered. In this specific case, the local dynamic loads and acceleration of the flap system are significantly affected by the structural behavior of the component chain landing gear, fuselage, wing, wing-flap-interface, flap support and the flaps themselves. The dynamic response behavior of the flaps is particularly nonlinear due to bearing friction and backlash and bracings within the wing-flap-interface.
In order to investigate the dynamic effects on the flap system in the early stages of design, as well as attendant to the certification process, the Institute of Aircraft Systems Engineering in collaboration with the Airbus Deutschland GmbH develops a tool chain for generic modeling of multi-body structures for the simulation environment MSC.Adams. The degree of abstraction of the individual subsystems and their components can, according to the existing data, models and the required accuracy, simply and quickly be adapted. Hence, parameter studies and uncertainty analysis are simply realizable. Similarly, it is possible and necessary to implement boundary conditions like wing deflection or loads on flaps in order to investigate specified load cases. Therefore, the main task of this and future work is the advancement of generic model building and the prediction of loads and accelerations working at the flap system as a result of ground loads.

1. INTRODUCTION

The development of flap mechanisms of modern transport aircraft is a challenging, iterative and error-prone process where design decisions are to be made a long time before the system behavior and its structural integrity can be inspected by ground tests or even flight tests. Furthermore the development process of aircraft systems is subjected to a rising pressure of meeting development and delivery schedules as well as a pressure to more economic operation.

Computerized methods such as CAE-Methods are a key technology in improving the development process by accelerating design decisions, reducing uncertainties and gaining system insight. While methods for representing the system geometry, CAD-methods, are mature, methods for representing and predicting the system behavior, simulation methods, are much harder to deploy but still nowadays offer a high potential for improving the development process.

An important quantity of influence in the design process of flap mechanisms are loads that occur in the components of the mechanisms, so-called interface loads. Today, linear Finite-Element methods are used to predict static interface loads. However, a lack of methods exists for prediction of dynamic loads occurring in failure cases and ground maneuvers. Dynamic failure cases in the mechanisms result in the activation of safety devices and temporary high peak loads that can be dimensioning in design. Ground loads, on the other hand, especially a landing impact and runway bumps, can have a similar impact on the system behavior. Furthermore, tests revealed that in certain system regions kinematic effects and effects like friction and backlash can strongly influence static and dynamic interface loads.

Consequently, there is a necessity for additional modeling and simulation methods that offer an adequate level of detail and produce results in tolerable simulation time. As shown in section 3 of this paper, the method of elastic multibody simulation is chosen for this purpose. However, flap mechanisms are systems of high complexity and high criticality. In order to maintain the confidence in methods developed, a thorough validation of methods and simulation models is necessary while stepwise increasing system complexity and relying on already validated methods and submodels.

The work at the Institute of Aircraft Systems Engineering is separated to two subsequent research projects named VIVACE and HIT. During the research project **VIVACE**, efforts focused on the development and validation of methods for mapping a certification relevant dynamic ground test, the drive strut rupture test (see section 3).

This particular test was chosen for two reasons: Firstly, the test environment offers simplified and measurable boundary conditions, such that validation efforts could be centered to the particularities of the flap mechanism. Secondly, due to the high dynamics this test is assumed to put the highest requirements to the stability and robustness of a numerical simulation.

In particular, a tool (PreMBS) was developed for parameterized multibody model generation and a fast modification of model structures and parameters, based on methods presented in [12][19]. A model of the complete test environment was implemented in PreMBS, transformed into a multibody model in MSC.Adams and validated by test results. This part of the work will be presented in detail in section 3 of the paper. It was shown that results of high accuracy can be achieved by a stable numerical simulation.

Further work in VIVACE concerned the development of methods for estimating the effect of parameter uncertainties that offer the potential to study the variation of simulation results due to uncertainties as well as the influence that each parameter uncertainty or a combination of uncertainties exert on specific spread of simulation results. Additionally, the work in VIVACE concerned the integration of fine mesh Finite Element flap models into the multibody environment, [14][15], the integration of distributed aerodynamic pressure loads occurring in flight conditions on both stick and fine mesh models and the modeling of a wing deformation, [21].

The results and methods from VIVACE are used and extended within the project **HIT**. In a first step, the modeling methods for wing deformation and aerodynamic pressure integration are to be validated by results of a flight test configuration. For this reason, methods from VIVACE are applied and adapted to different input data structures for aerodynamic loads and wing deformation. Meanwhile, the usage of the complete, already validated model of the flap mechanism significantly reduces the uncertainties in this extended validation step.

Additionally, a major aim of the work within HIT will be the simulation of ground loads, in particular the determination of interface loads in the flap mechanism that result from ground maneuvers such as a landing impact. Several publications [16][17][18] concentrated on mapping ground dynamics of an aircraft in multibody simulation, while [16][18] considered the development of methods for representation of aeroelastic loads on a model of the complete aircraft. The extended approach to gain insight in the effect that ground dynamics exert on interface loads in flap mechanisms is a promising step to improve the development process of high lift systems.

2. THE FLAP SYSTEM OF THE A380

The high lift system of the A380 consists of eight slats and three flaps in single fowler configuration at each wing. Due to the topic of both projects, modeling the flap system of the A380, the slat system will be omitted in this work. The labeling of the flaps follow from their spanwise geometrical location at the wing, so the flap nearest to the fuselage is the inboard flap, the one next to that is the midboard flap and the farthest external one is the outboard flap. Each flap is supported by two support mechanisms, often simplified referred as tracks. Whereas the first one is attached to the fuselage, the remaining five ones are attached right to the wing (FIGURE 1).

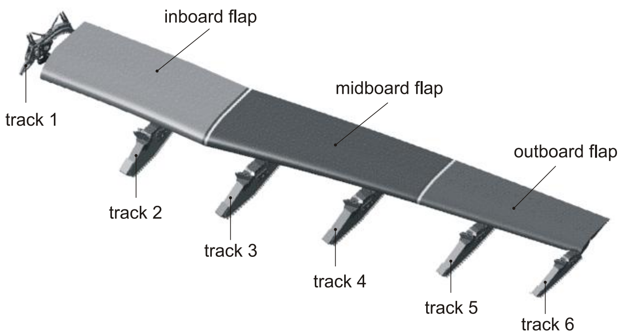

FIGURE 1. A380 flap system

Support station one differs from to the rest of the support stations, on one hand in the attachment right to the fuselage and on the other hand in its general design. A more detailed description is omitted at this point because of its complexity and the lack of assistance in understanding the latter models and simulations.

Support stations two to six are designed in an almost identical way but scaled different in size. Each of these five support stations is connected to the wing at four points, one point for front attachment and three points for rear attachment. The flaps themselves are attached via the drive strut, the carriage and the rear link. The drive strut is the connector between the flap leading edge and the rotary actuator with its actuator lever. The rear link is attached directly between the flap trailing edge and the trackbeam. In contrast, the carriage is mounted translational moveable to the trackbeam (FIGURE 2). By means of these kinematic mechanisms, the typical fowler motion is realized, first an increase of wing area due to wing chord extension and second an increase in wing camber by flap rotation. The maximum flap angle in extended position is 33°.

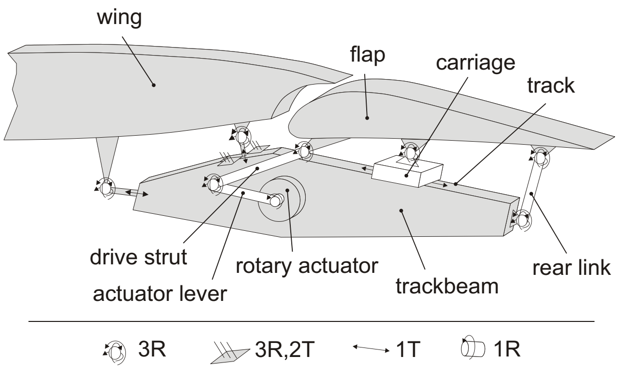

FIGURE 2. Schematic illustration of the kinematics at track two to six

The flaps are driven synchronically by a central located hydraulic power drive unit, the PDU. The rotation of the PDU is transmitted via gearboxes and transmission shafts to the rotary actuators of the distinct support mechanisms (FIGURE 3).

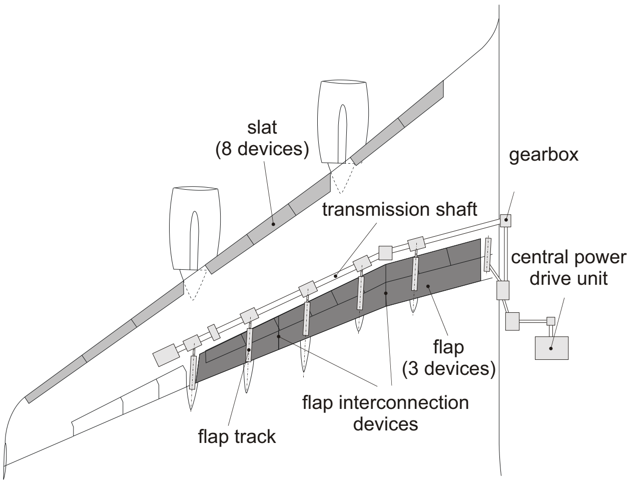

FIGURE 3. Schematic illustration of the A380 high lift system

A moreover very important component of the A380 flap system is the flap interconnection mechanism (FIGURE 4). This mechanism is located between the inboard and midboard flap as well as between the midboard and outboard flap. Besides providing an aerodynamic sealing for the area between the flaps, the main purpose of a part of this mechanism, the interconnection strut, is the coverage of actual flap position in case of a drive strut rupture. In this particular circumstance the interconnection strut acts as second load path by transmitting the loads into the flap next to the defective support station. Simplistically, the interconnection strut is a rod in a housing which is able to move due to its no-load stroke. Therefore, under regular conditions the strut is free of load. In case of failures, however, the flap is accelerated strongly by external loads. The resulting crash at one of the two inner contacts of the strut introduces an enormous impulse into the flap system. To town down these high load factors a crash element is part of the interconnection strut, which is designed for absorbing the emerging kinetic energy. After detection of such a failure, the entire flap system is stopped to prevent asymmetrical flap configuration.

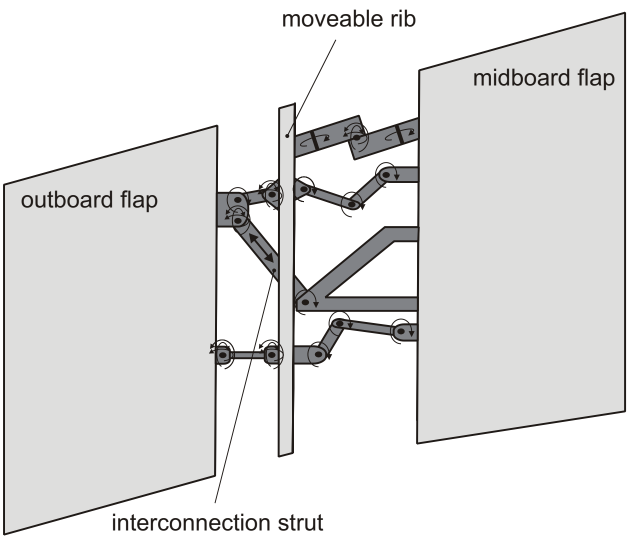

FIGURE 4. Flap interconnection mechanism between midboard and outboard flap [20]

3. INVESTIGATION IN TEST RIG CONFIGURATION (PROJECT VIVACE, AUTHOR: H. GUELZAU)

The research activities within the project VIVACE mainly focused on mapping a test rig used for system certification. Compared to the flap system in flight configuration, where unsteady aerodynamic loads and significant wing deformation affect the system behavior, the boundary conditions of the present test rig are much simpler and can be approximated with less uncertainty: On one hand, external loads imposed by pneumatic cylinders, FIGURE 5, can be modeled by concentrated forces whose magnitudes are known from measurements at the test rig. On the other hand, the steel frame of the test rig, FIGURE 5, is approximately stiff, such that the trackbeams can be considered invariant in their positions.

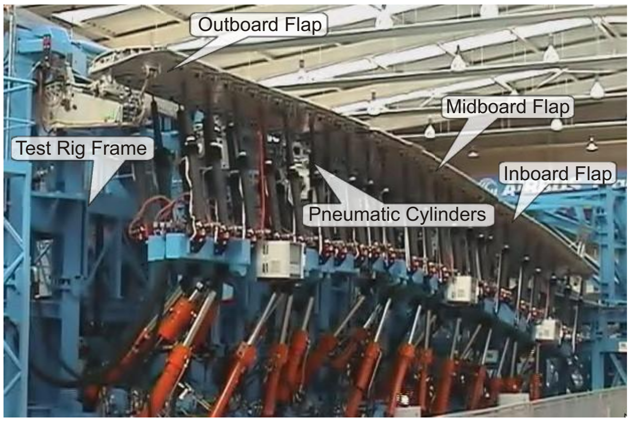

FIGURE 5. Certification Test Rig

3.1. Project Aims and Description

Besides the development of methods for modeling and simulation of the flap mechanism for the purpose of determination of dynamic loads, a major project aim was to increase the confidence in methods, models and simulation results. In particular, it has to be shown by comparison of simulation and test results that the system can be mapped with sufficient accuracy for a high number of measurements in different test configurations. Besides the correct implementation of the model in simulation software the main challenge in mapping the system is a proper system abstraction from the real system to the conceptual model [6]. This means that those physical effects and system regions have to be identified which have the highest impact on the overall system behavior. However, a system including too many structural details is risky in case of error-proneness and debugging [7], such that a minimal model of the system investigated is necessary. Obviously this demands frequent changes in model structure and model parameters as well as subsequent evaluation of the change impact. Methods for effectively do this are of high necessity.

A solution commercial of the shelf (COTS) is chosen, which means that commercial specialized simulation software is to be used and to be extended if necessary. There exist several methods for mapping the system dynamics of a flap mechanism where elastic deformations of parts as well as nonlinear, large scale rotations occur. One alternative is the geometrical nonlinear Finite-

Element Method (FEM) [1][2], another one is the Elastic Multi Body Simulation (EMBS) [3][4]. In this case, the EMBS method is chosen since models are rather simple and parametrizable. In addition, the EMBS-software MSC.Adams is picked due to its wide distribution in industry. Flexible bodies are integrated via the floating frame of reference approach [3], which is equivalent to large deformation FEM as long as relative nodal rotations vanish [5][8]. It is assumed that the rotations mentioned are sufficiently small for all elastic bodies used, such that a negligible error is introduced. For the flap bodies and the beams of the support mechanisms it is expected that their deformation affects the simulations results such that these bodies are modeled by flexible bodies.

As the following paragraphs will demonstrate, methods for modeling were developed and implemented which highly improved the investigation of present system. For future aircraft projects these methods have the ability to effectively support the calculation of dynamic loads.

3.2. Methods for Modeling Elastic Multibody Systems (PreMBS)

As mentioned the process of finding a proper model structure requires frequent changes in model topology and parameters until a proper model is available, which correctly maps various test results. Furthermore, different boundary conditions and test configurations have to be modeled using the latest model structure and different input data must be processed before included by model parameters. The modeling process in addition consists of repetitive modeling operations in submodel level as well as in basic model element level. Hence, the modeling process is a very time consuming task and it is hard to always keep latest version of input parameters, assumed parameters and model structure for all necessary model configurations.

For this reason, the preprocessing tool PreMBS was developed and implemented in Matlab which significantly reduces the modeling effort and keeps a structured, text-based representation of the model. Basically this tool offers a software-independent, object-oriented data format for general EMBS models as proposed in [12], which is compiled to the data format specific to the simulation software.

As shown in FIGURE 6, the data format consists of files that determine the structure of a MBS submodel (template files), in particular the general characteristics of parts, joints and forces, and files that contain all the relevant numerical data of a submodel (subsystem files), for example locations of kinematic points, spring stiffnesses or friction coefficients. Assembly files in turn reference subsystem files, interconnect the resulting submodels and thus lead to the complete description of the EMBS model. The file that results from compilation can directly be imported into the script executable EMBS software. Multiple subsystem files can thereby reference to one template file, FIGURE 6.

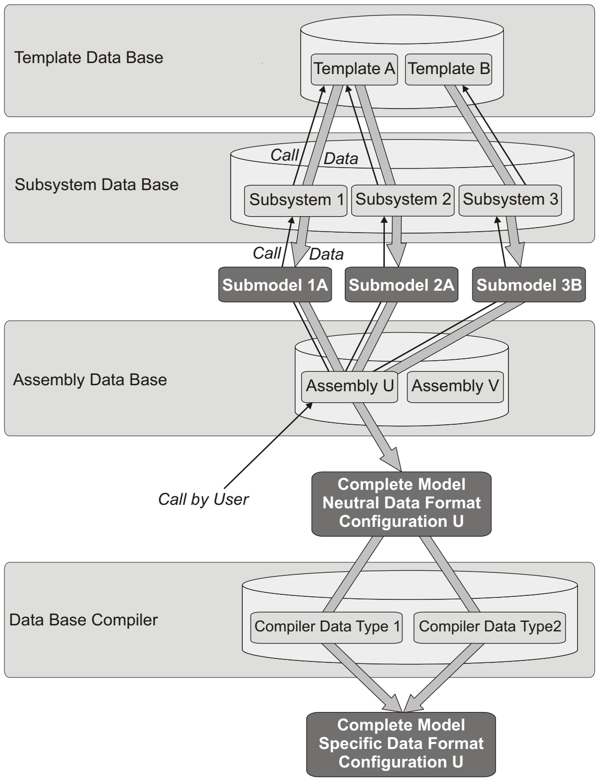

FIGURE 6. Structure of PreMBS

A further increase in efficiency is achieved by the template-specific data types, describing the distinct properties of bodies, joints or external forces. These data types require a minimum amount of information, and a change in level of detail can be realized by simply switching a flag [10].

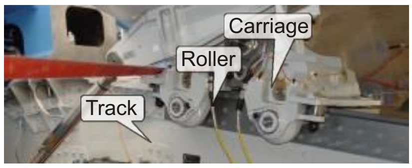

FIGURE 7. Connection from the trackbeam to the carriage of a support mechanism

For instance, the connection from the track to the carriage of a support mechanism, FIGURE 7, is designed by 12 rollers allowing a relative translational motion. This can be modeled by an ideal translational joint, but in reality, there exists a certain elasticity, joint clearance and friction force between the rollers and the track surface. In general, the model must be modified and simulation results must be evaluated in order to get an idea of what model detail is necessary. A model modification directly in the simulation software is a very time consuming task and often requires writing complex functional terms which are error-prone and need an individual verification. The previously defined model structures of PreMBS only need the decision of what level of detail to include and the provision of the relevant parameters. However, it is still a difficult task and requires profound system experience to answer the question of what level of detail to include into a proper global model. An environment for modeling, simulation and results evaluation will support any decision of this kind by quantitative results.

3.3. Method Validation

The model used for validation results from an iterative process of model structure and parameter identification. This process was conducted manually, but the usage of parameter identification algorithms as in [11] is promising. However, above presented modeling tool significantly reduced the effort of this identification process.

Test results used for the validation presented here concern two distinct test configurations: The first test configuration concerns a highly dynamic drive strut rupture scenario. In this case, a drive strut (here: drive strut 2 of the inboard flap) is replaced by an electronically activated buckling device, which is actuated while the mechanism is subjected to high external loads. The free flap end is afterwards accelerated by the external loads, until the relative flap movement exceeds the free movement of the interconnection strut and a mechanical stop is reached. The corresponding impact force spreads out in the adjacent mechanism parts and causes high peak loads in the parts which can be dimensioning in component design. The test configuration was mapped with high analogy by the simulation model, as shown by FIGURE 8 and FIGURE 9. These figures present normalized test and simulation results as well as a tolerance band resulting from measurement inaccuracies and an admissible simulation error of 8%. The drive strut forces F_{ds}, FIGURE 8, show high peak loads for tracks 1, 3 and 4. Peak loads as well as static loads before and after the impact are mapped within the tolerance band. The results of the force F_{ics} and stroke l_{ics} of the adjacent interconnection strut are shown in FIGURE 9. Again, test and simulation results show a high correlation.

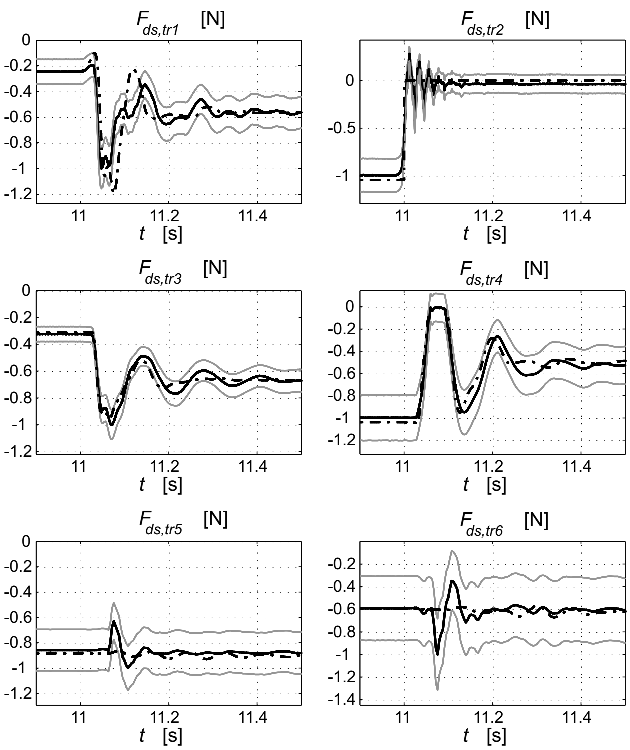

FIGURE 8. Test results (solid black line), simulation results (dashed black line) and tolerance band (solid grey lines) for dynamic drive strut rupture test: drive strut forces F_{ds}

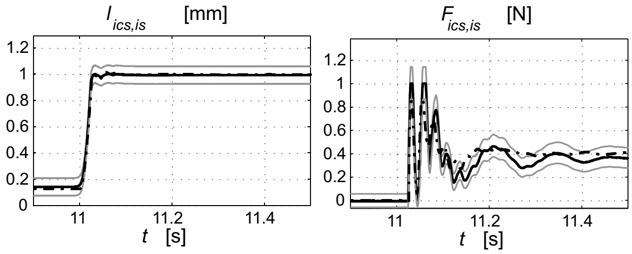

FIGURE 9. Test results (solid black line), simulation results (dashed black line) and tolerance band (solid grey lines) for dynamic drive strut rupture test: Force F_{ics} and stroke l_{ics} of inner flap interconnection strut

The second test configuration is about a failure test which is quasi-static, but puts high requirements to the accuracy of the model structure and certain model parameters like the dynamic test mentioned above. This test is called a failure detection test: The drive strut of one support mechanism is dismounted (in this case drive strut 1) before the mechanism is loaded by low external loads. Afterwards, the flap system is moved from retracted position to the landing configuration. During this extraction process, the stroke l_{ics} of the interconnection strut is different from the stroke of an intact system and after a while, the mechanical stop of the interconnection strut is reached again, this time with a much lower velocity compared to the dynamic case. The validation results for this test configuration are shown in FIGURE 10 and FIGURE 11.

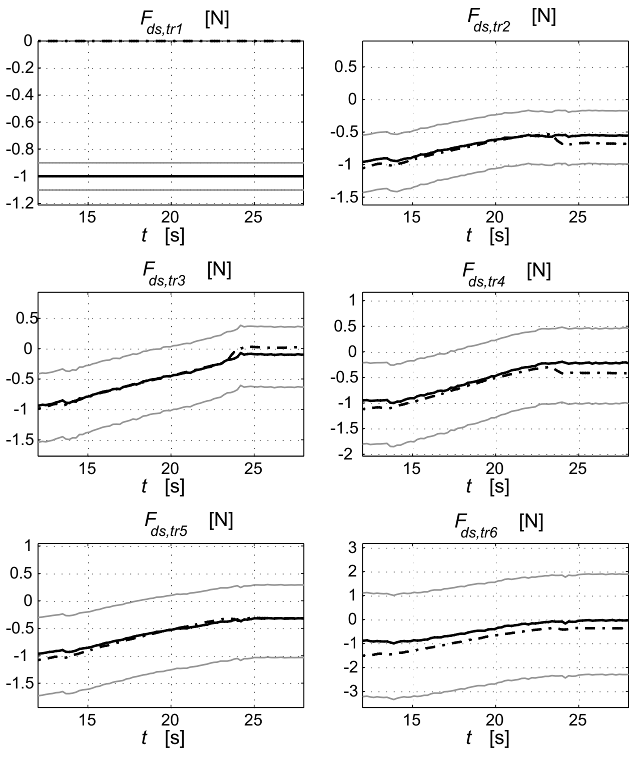

FIGURE 10. Test results (solid black line), simulation results (dashed black line) and tolerance band (solid grey lines) for failure detection test: Drive Strut Forces F_{ds}

Again, forces F_{ds} in the drive struts, FIGURE 10, are mapped with a high accuracy; the deviations are much less than tolerable limits. The corresponding force of the interconnection strut F_{ics}, FIGURE 11, shows that the time t_{detect}≈23 [s] of failure detection is correctly mapped in simulation. A simulation result, which turned out to be very sensitive to parameter variations, is the stroke l_{ics} of the interconnection strut. The tolerance margins are very low in this case, but still the majority of simulation results is within the tolerance band.

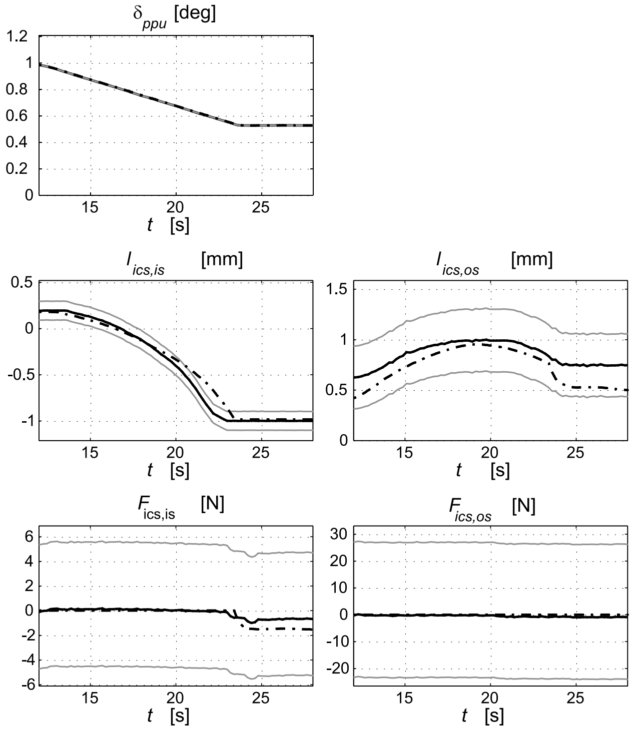

FIGURE 11. Test results (solid black line), simulation results (dashed black line) and tolerance band (solid grey lines) for failure detection test: Forces F_{ics} and strokes l_{ics} of flap Interconnection Struts.

Validation activities were accomplished for a much higher number of test configurations with different load levels and different failure conditions [13]. It turned out that for a high number of test conditions, the model developed correctly predicts the test results. Limits of the model become obvious in configurations with extremely low or vanishing external loads: In these cases, it seems that the test results are very sensitive to kinematic and friction parameters and hence, with limited knowledge of these parameters, the accuracy of simulation results decreases.

4. INVESTIGATION IN FLIGHT TEST CONFIGURATION (PROJECT HIT, AUTHOR: M. NEUMANN)

4.1. Project aims and description

After choosing and evaluating an appropriate modeling technique and mapping the A380 flap test rig in VIVACE the main focus within the project HIT is the extension of this technique and the modeled flap system. Having the capability of investigating real dynamic failure and load cases is the basis for designing more effective flap systems and therefore more efficient airplanes. In account to this question the effects of ground loads, especially the landing gear impact, are of particular interest in this project.

The main problem of modeling and simulating a flap system under real flight conditions are the boundary conditions. In comparison to the test rig, where no wing deflection is applied and the aerodynamic loads are measured during application at a discrete number of points, the wing deflection of the A380, FIGURE 12, is not negligible and the airloads acts two dimensional.

As a result of the mentioned character of the boundary conditions it is difficult to generate highly reliable measurements in flight at reasonable expense. So, numerical simulations are widely used. However, the generated input and reference data used for modeling and validation is much more uncertain compared to test rig configuration.

FIGURE 12. A380 with fully extended flaps before start

According to the requirement of using the modeling tool already in early design phases and besides the process of certification, it is necessary to handle input data of different complexity and accuracy. This data could be design loads as well as test and numerical simulation data. According to these circumstances different modeling techniques for applying boundary conditions are developed and will be presented in this work.

The following paragraphs will show a small overview of the realized load modeling techniques for providing wing deflection and airloads to the already discussed flap system. Afterwards, simulation results of the implemented techniques will be presented.

4.2. Methods for loads modeling

At the beginning of load modeling the question of existing input data of boundary conditions and subsystem models arises. In addition, the accuracy and reliability of the generated simulation results has to be taken into account since the increase in modeling detail results in a boost of required simulation time and therefore hardware resources, too.

4.2.1. Loads on wings

The wings of today's aircraft are highly flexible due to their enormous size and lightweight construction. The acting air and inertia loads are causing a strong deflection of the flexible wing. Thus, accounting of rigid wing characteristics in test rig configuration simplifies the boundary conditions significantly. The resulting deformation of the wing primarily consists of bending about the aircrafts flight direction axis and torsion about the wings spanwise axis, which is caused due to the shift of the center of pressure respective to the wing's neutral axis. In company to these local changes in pitch angle, lift and therefore deflection change.

Two basic procedures for modeling wing deformation are obvious, on one hand the direct specification of deflected flap interface points and on the other hand the use of a flexible body [3]. For modeling of in-flight load cases a model of the flexible wing is sufficient, but for modeling of ground load cases a flexible airframe is needed.

The first method, the integration of wing deformation data, was originally developed in VIVACE, [21], and was adapted within HIT to different input data.

For the purpose of realizing a direct position specification of flap interface points, movement of these points along a curve in space has to be known initially. The needed input data could be derived by numerical calculations as well as flight tests. As a result of the different curves in space of the particular interface points, the flap system will be bent and twisted.

The second approach, using a flexible wing or airframe model, is completely different. Whereas in direct position specification method the deflections are calculated or measured before simulation, this task is now done on the fly. In order to use the flexible models in the multibody environment MSC.Adams, the airframe model, like the model for each flap and trackbeam, has to be preprocessed via dynamic condensation [3][4]. Prior to this, the question of load application arises and is strongly affected by the character of the available loads and models. A closer look will be given in chapter 4.2.2, the modeling of flap loads. Generally, loads are applied directly to the flexible structure. As a consequence of this, the flexible wing or airframe and the attached flap system will be deformed.

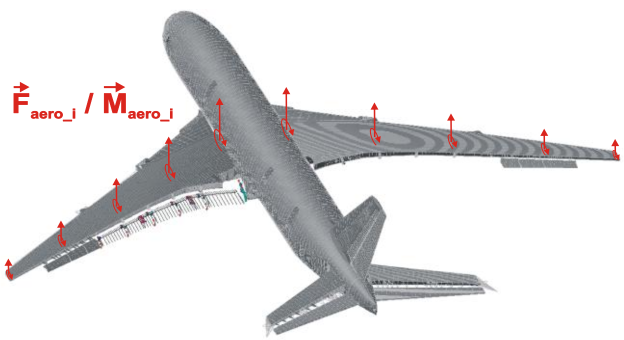

FIGURE 13. Loads on wings at wing reference axis (schematic)

According to the extension of the modeled flap system (chapter 3), both procedures were finally adopted. Input data for testing were derived from a nonlinear Finite Element analysis. For the first modeling approach, calculated wing deflection was used. Contrary to this, the flexible airframe and the airloads were taken for the second approach. The airloads are located at a geometrical reference axis inside the wingbox, which again is connected via rigid elements to the wing's front and rear spar for load distribution. In order to apply loads in MSC.Adams, every point of application had to be declared as external before condensation of the flexible airframe. The extended model, using the approach of flexible airframe, is shown in FIGURE 13. In addition, airloads at reference axis are pictured schematically.

4.2.2. Loads on flaps

As in the previous subsection already mentioned, the types of modeling of aerodynamic loads in MSC.Adams are mainly affected by the character of the flexible body. If flaps are realized as stick model, the possibility for assigning loads to each flap node is given, whereas in case of fine mesh model this procedure is highly impractical due to the large number of nodes. Every node or more specifically every necessary degree of freedom has to be declared as external to the flexible body. Consequently, the detail and size of the reduced model increases [8].

An alternative approach for the integration of loads are Modal Loads [8]. This element simplifies the modeling and simulation effort due to their dealing with loads. Instead of integration of individual load vectors, these vectors are combined to one global load distribution. This distribution has to be known initially for condensation, so it can be implemented directly into the load matrices of the reduced flexible body. Then, in multi body environment, modal loads can be easily scaled en bloc by user defined functions.

The two mentioned methods for reduction of distributed loads to concentrated forces on a stick model and modal loads that act at fine mesh models, [14], were originally developed in VIVACE, [21], and are validated and extended to different input data within HIT.

In VIVACE, design loads were used for modeling of aerodynamic flap loads. In contrast to these design loads, which are specified precisely and separate for each flap, real flight test data is normally known at just a few number of discrete points, due to the measurement effort. The pressure sensors are mostly located in chordwise direction at a small number of measurement stations in spanwise direction. In order to achieve a good quality of the reconstructed pressure distribution, most sensors have to be taken into account for interpolation. Due to this fact, all flaps and measurement data are transferred into the aircraft coordinate system according to their general coordinates η_{wing}. By this, the flap's relative positions to each other and the locations of the measurement stations are obtained. As a next step, the resulting points are projected to the flap chord area, which is defined by the flap's leading and trailing edges. After interpolation, aerodynamic pressure P at every flap point is known.

If fine mesh models of flaps are used for simulation, the calculated set of data can be used for defining modal loads (FIGURE 14). Using stick models of flaps needs further preprocessing (FIGURE 15), starting with the integration of the two-dimensional pressure distribution in chordwise direction. The resulting one-dimensional area load in spanwise direction can be separated into normal and tangential components respective to flap chord. Subsequent the loads have to be integrated in spanwise direction. As integration limits the centers between the neutral axis' points of the flaps are used. For applying the calculated loads vector F_{res_i} to the points of the neutral axis a compensation torque M_{res_i} has to be calculated by computing the cross product of $F_{T\_aero\_i}$ and $F_{N\_aero\_i}$ with the center of pressure respective to the neutral axis.

In order to achieve a continuous aerodynamic load, these tasks have to be performed for every flap configuration and interpolated afterwards.

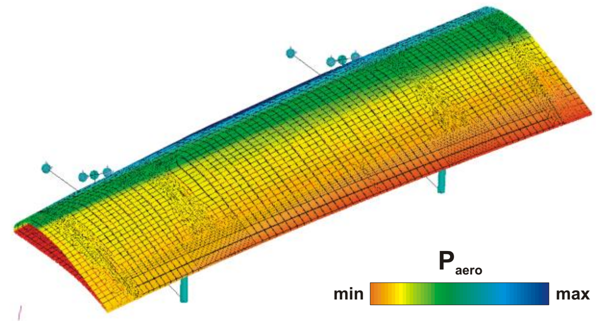

FIGURE 14. Loads on finite element fine mesh model of flap

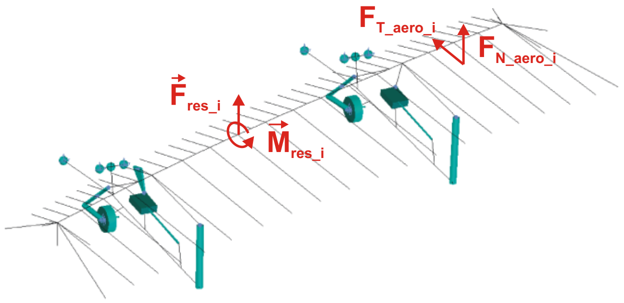

FIGURE 15. Loads on finite element stick model of flap

4.3. Validation of methods

For the validation of presented modeling techniques several simulations were created. The first test case should answer the question of correct wing deformation of the reduced flexible airframe. Hence, dynamic condensation was performed and results were imported into MSC. Adams. In comparison to the reference data, the nonlinear finite element calculation, loads and boundary conditions were applied similarly. The resulting deflection of the wingbox of the MBS and the FE calculation are shown in FIGURE 16, compared to the undeformed jig-shape.

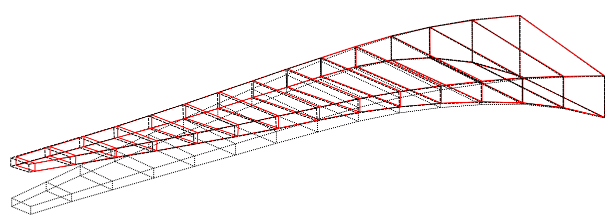

FIGURE 16. Comparison of calculated wingbox deflection: jig shape (dotted line), MSC.Adams (solid line) and MSC.Nastran (dashed line)

TAB 1 lists the correlated deflection variation of both calculations at wingbox center of the left wing tip. Generally it can be seen that the results show sufficient good correlation considering the large geometrical dimension and the reduction of model detail. In particular the torsion is mapped correctly.

	X [mm]	Y [mm]	Z [mm]
correlated deflection	246.6	119.3	81.7

TAB 1. Correlated deflection variation of nonlinear FE (MSC.Nastran) and MBS (MSC.Adams) calculation at wingbox center of left wing tip

The next two case studies will compare the presented flap load modeling techniques. Due to this, the studies are nearly identical with the only difference of the used type of flexible flap model. Thus, modeling of airloads differs, too. In order to reduce side effects as a result of the complete flap system only the midboard flap, their support stations, station three and four, and wing deflection were modeled. For the calculation of wing deflection the method of direct position specification was used [21]. In order to compare both techniques, load in drive strut and rear link of the supporting stations were measured during extension of the flap from refracted to fully extended flap position. The results of the drive strut measurement can be seen in FIGURE 17 and the ones of the rear link in FIGURE 18. The plots show the normalized loads vs. simulation time. As it can be seen, the results show good correlation. So both techniques can be used for modeling likewise.

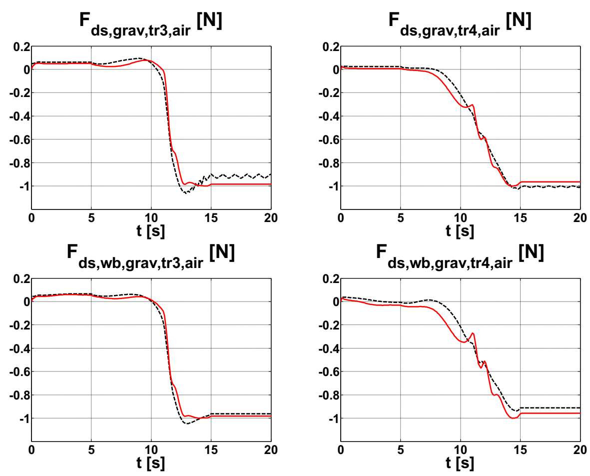

FIGURE 17. Loads in drive strut three and four due to airloads on stick (dashed line) respectively fine mesh model (solid line) with (b) or without wing deflection (t)

5. OUTLOOK

In the near future two important tasks have to be done. First, the mirroring of the left hand flap system to the right hand one and second, the implementation of landing gear models due to the examination of ground load effects. Afterwards, validation of the entire model has to be done by a huge amount of testing scenarios. In the distant future a realization of fluid-structure-interaction has been conceived, in order to generate boundary condition data with low uncertainty.

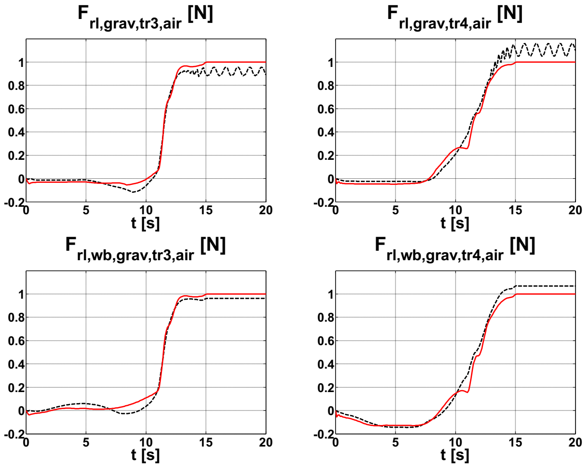

FIGURE 18. Loads in drive strut three and four due to airloads on stick (dashed line) respectively fine mesh model (solid line) with (b) or without wing deflection (t)

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