

Undamped Extension of a Nose Landing Gear

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1 Abstract

In aviation, components are categorized based on the consequences of a failure. This categorization significantly determines the development costs, test quantities and maintenance cost. A simulation can show how serious such a failure can be and thus simplify the classification of the components and finally may reduce costs.

This paper describes the simulation of the undamped extension of a nose landing gear of an aircraft. Normally, a hydraulic cylinder is used to extend the landing gear in a controlled manner. The simulation will investigate what happens when this hydraulic cylinder fails completely. Then the landing gear drops down when opening the flaps simply due to its own weight and pushes hard into its end stop. The simulation should show, if afterwards a safe landing is possible.

First, different analysis types or kinds of modeling are compared and evaluated for suitability to this application. In general, such a task could be solved with a multi-body simulation, with quasi static, implicit dynamics or with explicit dynamics. In terms of accuracy, effective modeling and computational effort, the decision was made for an explicit dynamic simulation with LS-DYNA.

The geometry handling and necessary model simplifications were carried out within the ANSYS Workbench and the calculation model was generated using the workbench LS-DYNA. Once completed, then it is very easy to make different model variations.

In particular, different modeling techniques for the many joints were studied. When using normal joints with `*CONSTRAINED_JOINT`, certain model parts are always set to rigid, which means that the assessment of a possible failure may be impossible. Various mesh options were also examined, in particular the suitability of different formulations of tetrahedral elements for complex geometry.

The comparison with the experiment showed a good agreement, but also deviations. By varying inaccurately known input parameters, e.g. friction values in the joints, it becomes visible, how robust such a simulation can be. From this, requirements for the experiment can be derived.

At the end we will point out that such simulation is suitable to classify failed parts. In this specific case, a save landing would be possible despite the failure of the hydraulic cylinder.

2 Introduction

The object of contemplation is the retraction actuator of a nose landing gear.



Currently this part is categorized in class 1. This means that the failure of the actuator leads to a failure of the chassis, which is a catastrophic event. Table 1 shows the categorization of components based on the consequence of a failure:

Classification of Failure Conditions	Allowable Qualitative Probability	Effect on Airplane	Effect on Occupants
No Safety Effect	No Probability Requirement	No effect on operational capabilities or safety	Inconvenience for passengers
Minor	Probable	Slight reduction in functional capabilities or safety margins	Physical discomfort for passengers
Major	Remote	Significant reduction in functional capabilities or safety margins	Physical distress to passengers, possibly including injuries
Hazardous	Extremely Remote	Large reduction in functional capabilities or safety margins	Serious or fatal injury to an occupant
Catastrophic	Extremely Improbable	Loss of aircraft	Multiple fatalities

The scenario of the current classification is based on following fault sequence: Because of the failure of the hydraulic supply, the suspension drops down freely due to gravity and air resistance. The actuator now may act passively as a damper.

A conservative analysis concluded that without this damper the forces would lead to the failure of the landing gear.

This classification of the actuator yields to high costs for design, approval, production and in-service.

The goal for a new, much more realistic analysis is to show, that in the case of a complete failure of the actuator and with no damping when extending, the landing gear nevertheless does not fail.

This analysis must be performed by means of a suitable numerical method and verification with tests. If successful, in future projects the actuator can get a lower classification, which will reduce development and detection costs.

Experiments have already shown that an undamped extension does not lead to the failure of the landing gear.

For certification, analysis supported by test is necessary. The basis for approval is a positive analysis. The analysis methodology must be verified by appropriate tests. In practice there are very high demands on the verification, especially for new methods.



3 Evaluation of the analysis method

Different analysis types are possible to simulate the load of the landing gear by such an undamped extension:

1. Implicit quasi static

Assumption: at the time of impact the entire potential energy is converted into deformation energy. This method is close to the previously used methods and is too conservative. Therefore, this is discarded.

2. Multibody dynamics with rigid bodies

Very short simulation time, but forces at the stop are infinitely high. Stresses in the components must be calculate separately. No energy dissipation due to plastic deformation. Therefore, this is discarded.

3. Multibody dynamics with flexible bodies

Forces would be more realistic, but joints are mainly ideal connections, no local stresses in the joint eyes predictable. No plastic deformation in the flexible parts. Contact between deformable bodies is a challenge. Therefore, this is also discarded.

4. Transient implicit dynamics

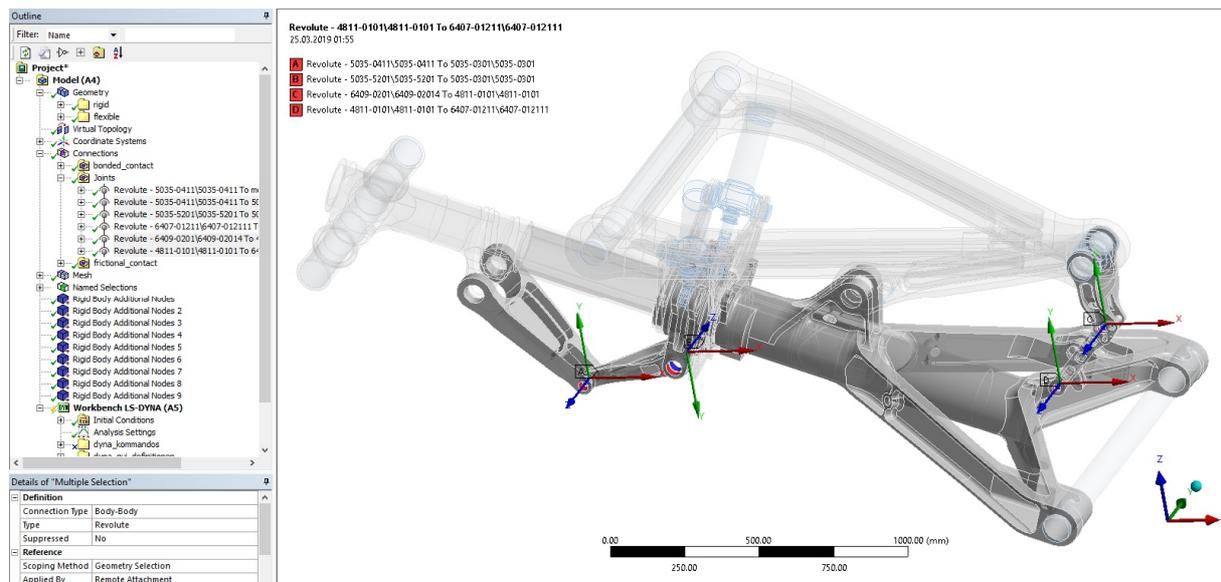
Not necessarily recommended in combination with expected plastic deformation and many contacts. Convergency trouble and long run times are expected. Therefore, this is also discarded.

5. Transient explicit dynamics

This is known as a suitable method for impact analysis. Elastic-plastic deformations and arbitrary nonlinear contact situations no problem. Therefore, this is the chosen method. But requires different modeling philosophy compared to implicit methods.

4 Model generation for LS-DYNA

Model generation was done in ANSYS Workbench LS-DYNA.



4.1 Assembly, components and functions

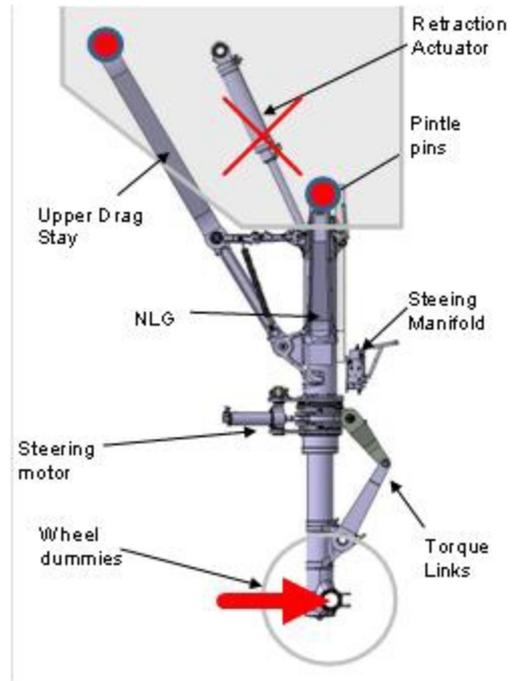
The actuator was not modeled because it is considered as completely failed.

The system is connected to the environment (aircraft structure) in 2 places with revolute joints (red)

The wheels are mass points.

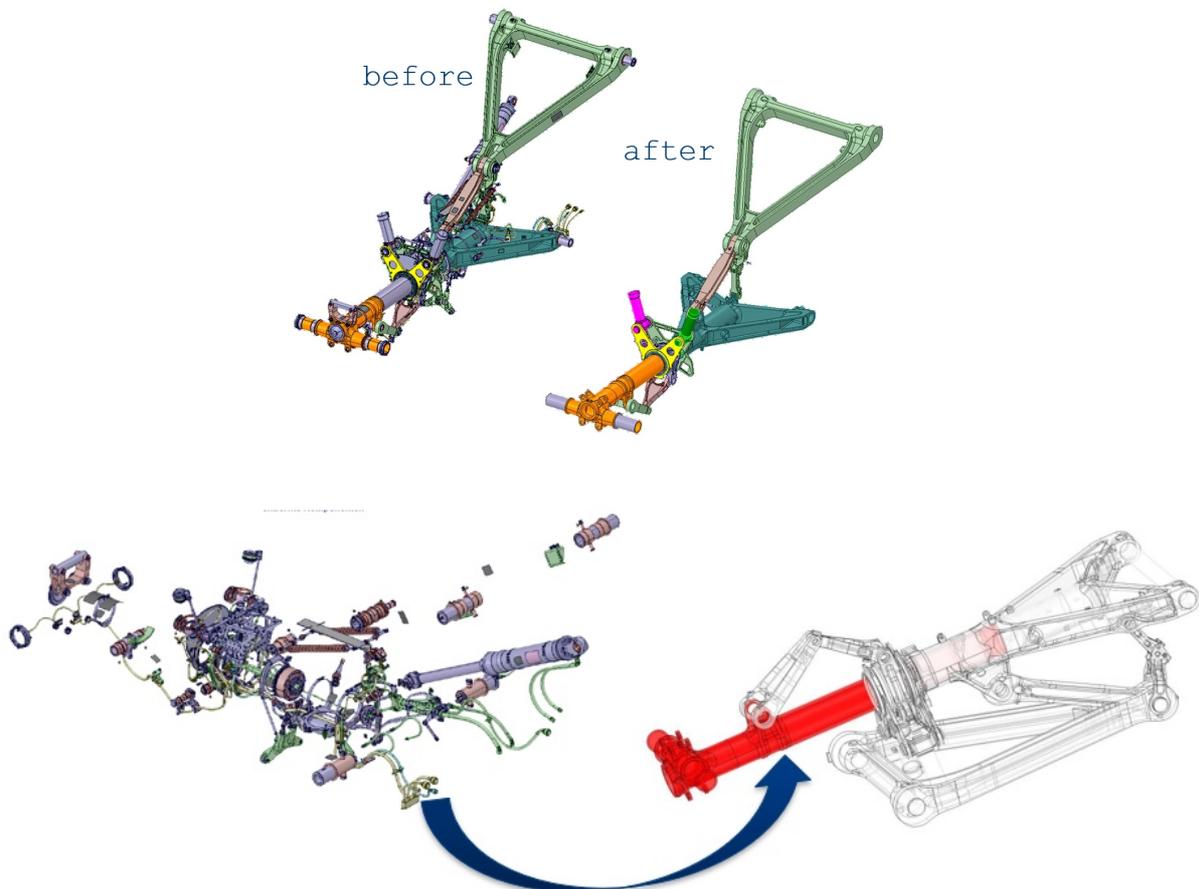
The aerodynamic load (from a CFD analysis) was applied at the wheels. It is depending on the position of the wheels.

All parts have elastic-plastic behavior.



4.2 Model simplification, mass matching

There are a lot of attachments, cables and hoses that do not contribute significantly to stiffness and therefore are not modeled with. Their mass is smeared onto the structure by `*ELEMENT_MASS_PART`.

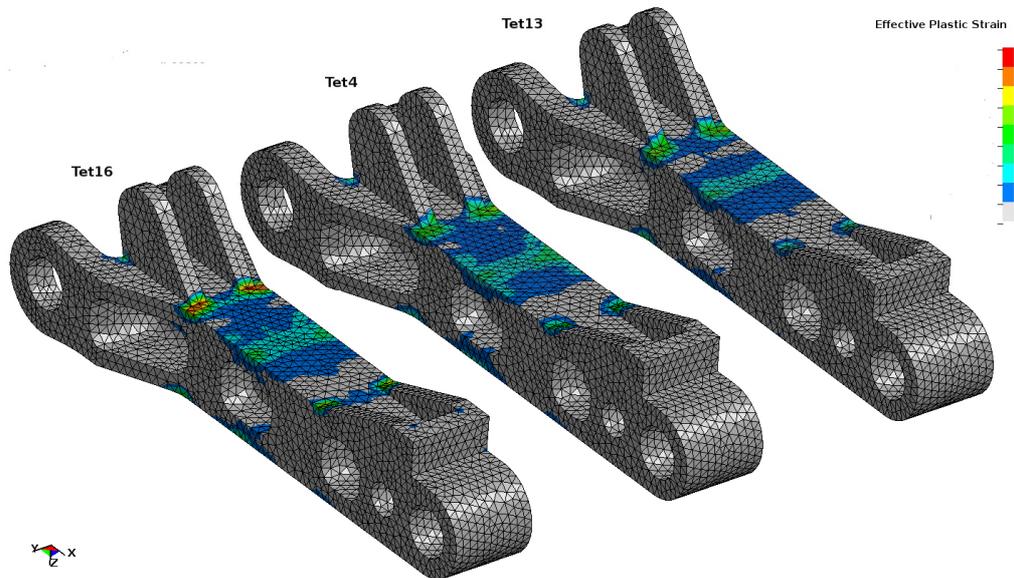


4.3 Element types and meshing

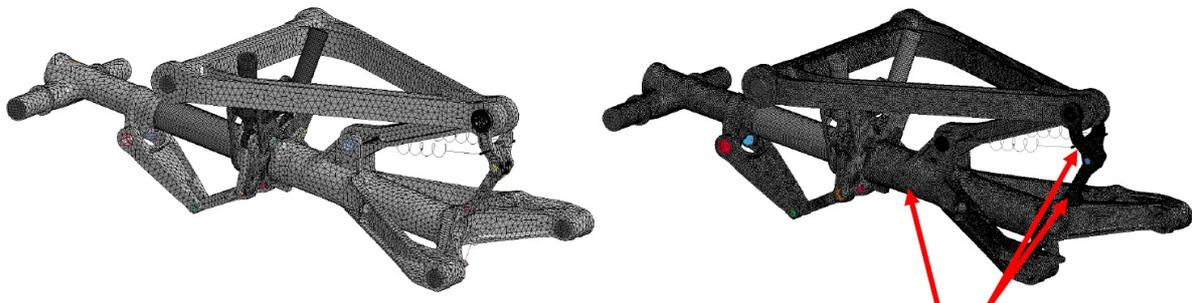
All parts where a structured mesh was possible, are meshed with hexahedrons (elform=1). But many parts are meshed with tetrahedrons. We tried the following choices:

- Linear tetrahedron (elform=13): very cheap, robust, less accurate
- Quadratic tet with rot's (elform= 4): more costly (factor 4), more accurate
- Quadratic tet's with midside nodes (elform=16): most costly (factor 8), best accuracy

For the most heavily loaded parts we have checked the influence of these element types. Summary: If the mesh is fine enough (5-10mm), then the cheap elform=13 is sufficient to detect the problematic locations. That's a good compromise between effort and benefits. For a final certification there is still the option to use the most accurate element type with the corresponding costs.



For a first trial run a pretty coarse mesh was used, which results in 140 000 elements. The final fine mesh consists of approximately 1 million elements, where particularly heavily loaded or particularly interesting zones were refined again.



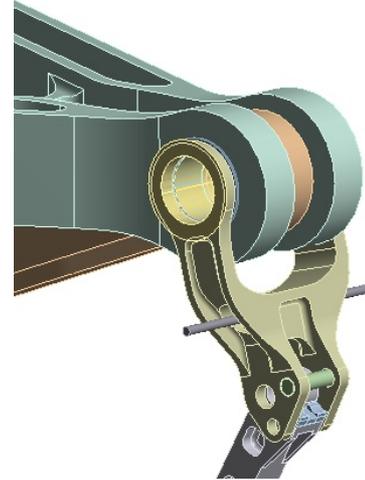
The model with the coarse mesh runs in 7 hours by using 16 cores in parallel. This model is sufficient to calculate the forces acting on the interface to the airplane body.

The model with the fine mesh needs 28 hours on 32 cores in parallel and is necessary to calculate stresses in the interesting parts of the landing gear.

4.4 Modeling of joints

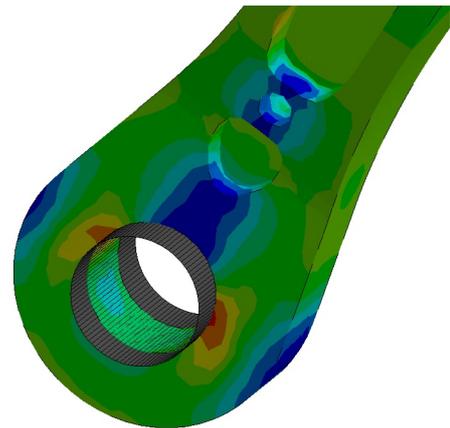
Only lightly loaded connections are modeled as simplified joints using the ***CONSTRAINED_JOINT** keywords. The disadvantage is that it stiffens the neighborhood of the joints, because joints must be connected to rigid bodies. The definition of such simplified joints can be done very conveniently in ANSYS Workbench.

Heavily loaded connections and important joints where more than two parts are connected, are modeled with nonlinear contact: The bolt is assumed to be much stiffer than the hinge eye, so it can be rigid, meshed with shell elements on the outer surface. The contact between hinge eye and bolt is modeled with ***CONTACT_FORMING_NODES_TO_SURFACE_SMOOTH**. This ensures a smooth contact surface without facets for accurate sliding, without expensive computational cost.



This modeling is the only way to get realistic stresses in the hinge eyes, by the absence of rigid regions. The rigid bolt thereby increases the local load, i.e. that's a conservative approach.

The picture shows the 1st principal stress in the contact area with the bolt, which could be a source of failure.



4.5 Modeling of the aerodynamic load

The nose landing gear always opens against the flight direction, the aerodynamic load is important.

The force acting on the wheels are calculated in a separate CFD analysis for different angle of extension φ as a steady state answer.

The moment acting on the complete landing gear (as a rigid body) is converted in a force acting on the axle of the wheels. We assume that the largest part of the air resistance comes from the tires.

These values (force over angle) are written into a ***DEFINE_FUNCTION_TABULATED**.

A ***DEFINE_FUNCTION** is used to calculate the angle φ during the simulation and to transfer the load to the COG of the wheels with a ***LOAD_RIGID_BODY**.



5 Results and verification

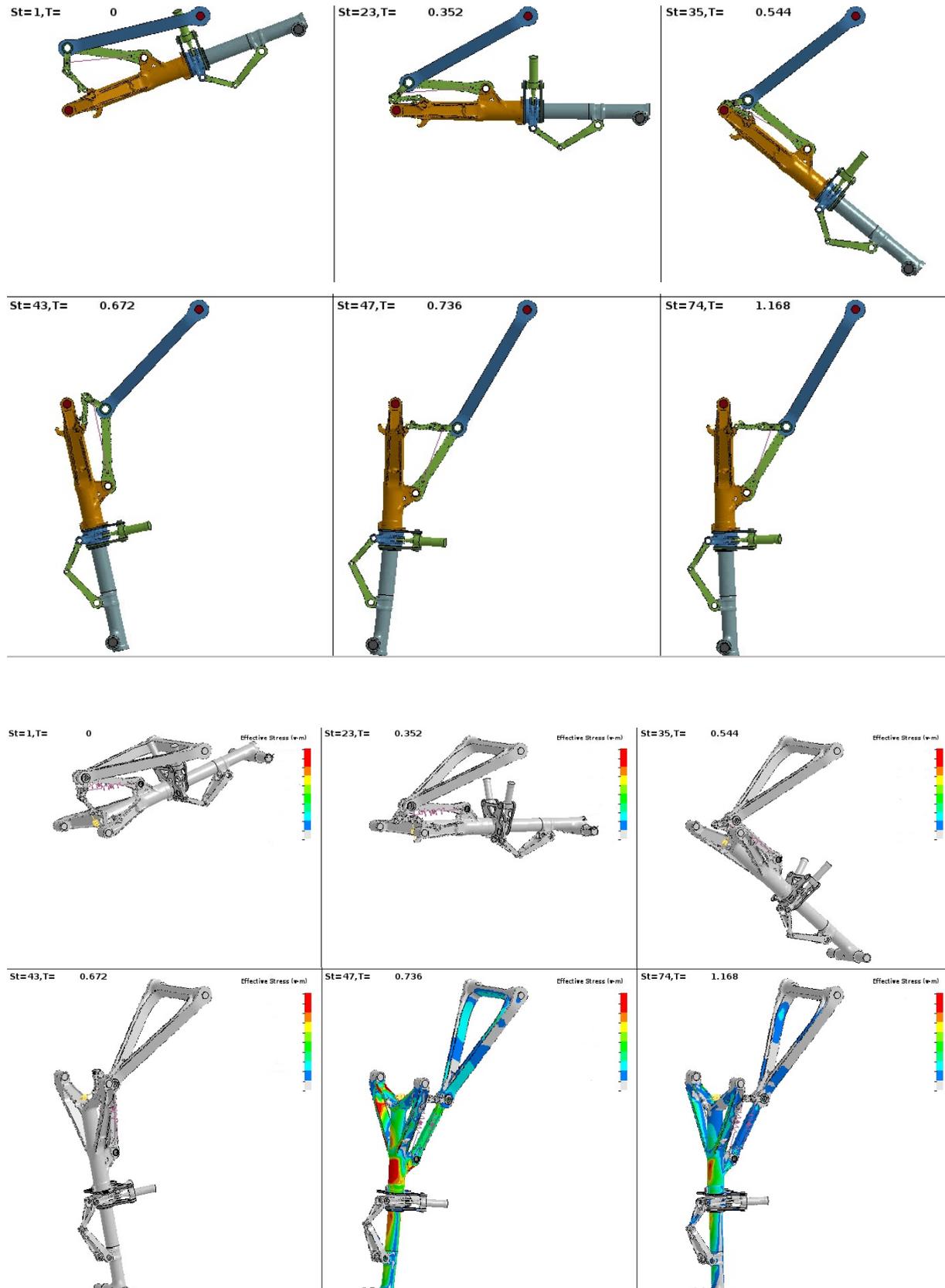
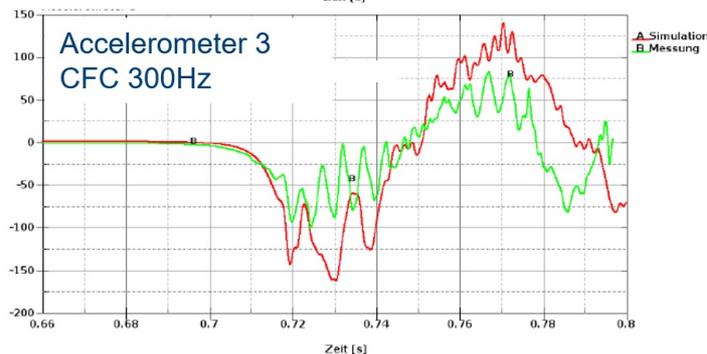
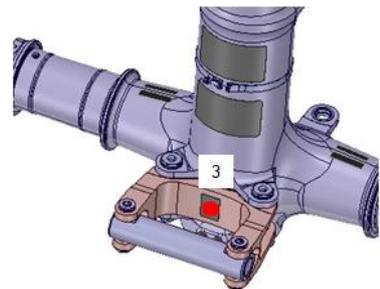
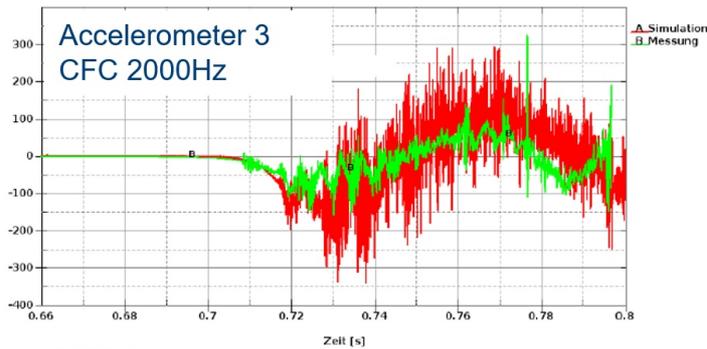
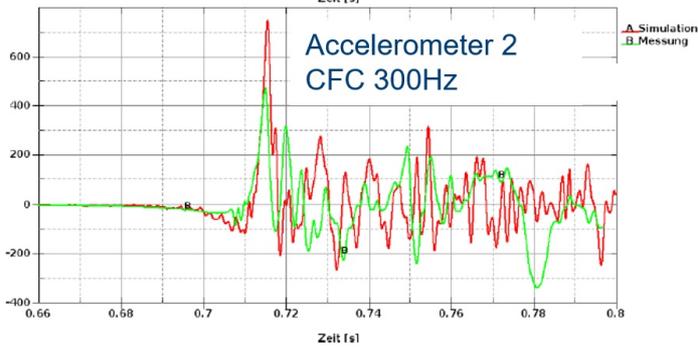
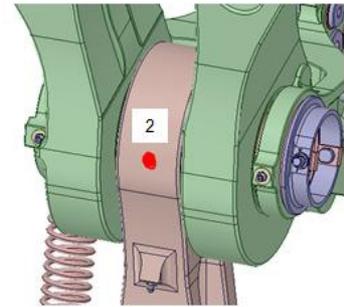
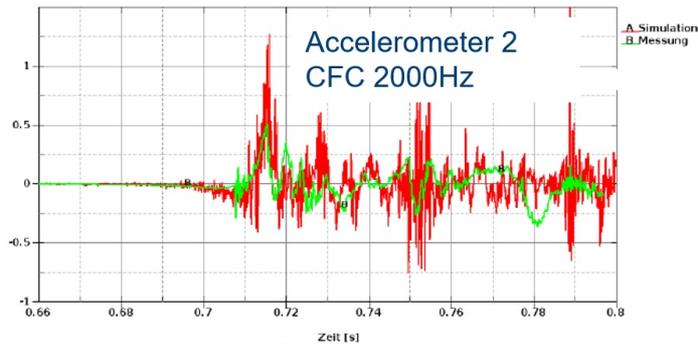


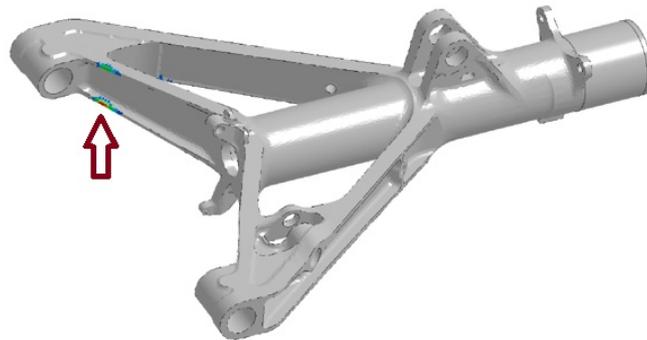
Fig.1: Animation of the undamped extension of the nose landing gear

Purely visually, the sequence in the simulation looks like the video of the experiment. Also, the timing is comparable: It takes approximately 0.7 second to reach the extended position for the first time. Here it could be seen the influence of the aerodynamic load: without this load the landing gear needs 300 milliseconds more.

From the experiment, there are acceleration signals, measured by accelerometers at different positions, prefiltered with 10kHz. These signals are very noisy and therefore hard to compare. To compare measured accelerations with simulated ones we are using SAE filter CFC 2000Hz and 300Hz. With 2000Hz especially the simulated signal is much noisier than the experiment. We assume that mainly the rigid suspension in the FE model is the reason for that. Using 300Hz filter shows some agreement between simulation and measurement.

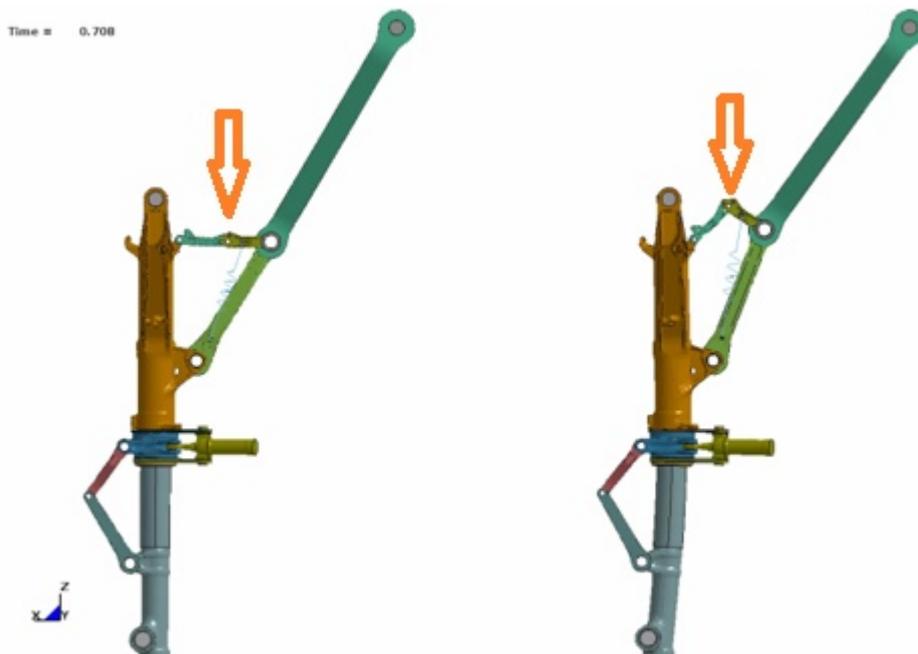


In the simulation, relevant plastic strains occur on one arm of the main body, which were not detected after the experiment. Again, here we assume that the total rigid suspension in the FE model is the reason for that. In general, this leads to a higher loading of the landing gear and makes the simulation more conservative.



In one point we can see a sensitive behavior of the model: Small differences e.g. in the meshing or modeling of friction lead to a different behavior of the locking strut. In some situation the locking strut locks immediately after the full extension and stays locked until the end. In other situation the locking strut springs up again because of the vibrations in its environment.

If the strut opens again after the first impact, significantly more energy is converted through joint friction. In opposite: Lock the strut immediately and remain closed, this leads to higher loads in the structure and is therefore more conservative. In the experiment, the strut opens again after the first impact, so the experiment does not show the most conservative situation.



6 Summary

The comparison with the experiment showed a good agreement, but also deviations. By varying inaccurately known input parameters, e.g. friction values in the joints, it becomes visible, how robust such a simulation can be. From this, requirements for the experiment can be derived.

At the end we will point out that such simulation is suitable to classify failed parts. In this specific case, a save landing would be possible despite the failure of the hydraulic cylinder.