

Validation and Verification of a Beam Model during the Development of an Aircraft Landing Gear

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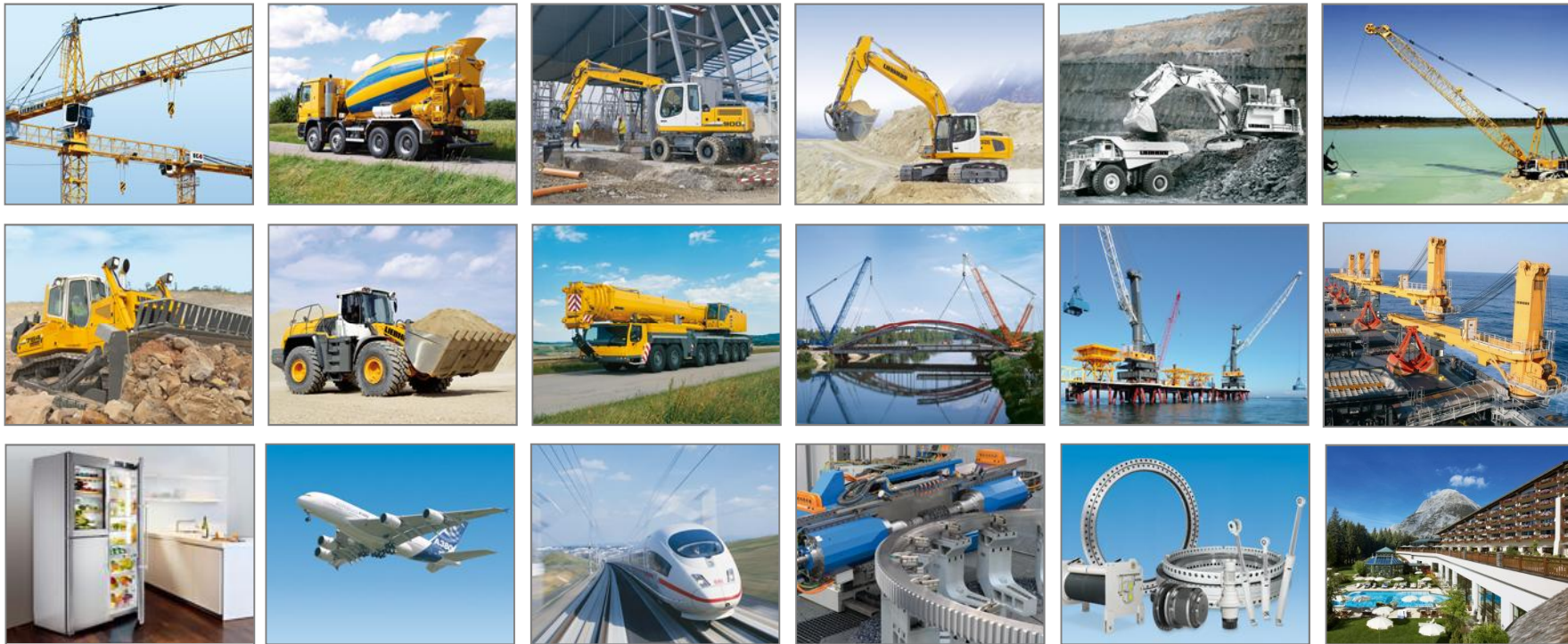
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Liebherr Group

Multifaceted Product Range

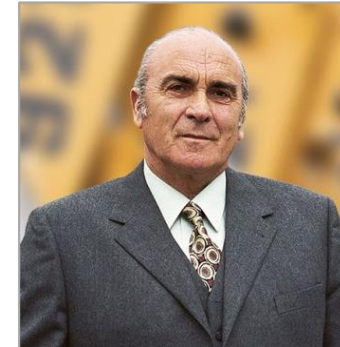


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Liebherr Group

Liebherr Group

- n Company founded in 1949 by Dr.-Ing. E.h. Hans Liebherr
- n Over 130 companies worldwide
- n More than 41,000 employees
- n About €9 billion turnover (2014)



Liebherr-Aerospace Lindenberg GmbH

- n Site: Lindenberg im Allgäu
- n More than 2,700 employees
- n About €600 million turnover
- n Products:
 - n Flight Control and Actuation Systems
 - n Landing Gear Systems



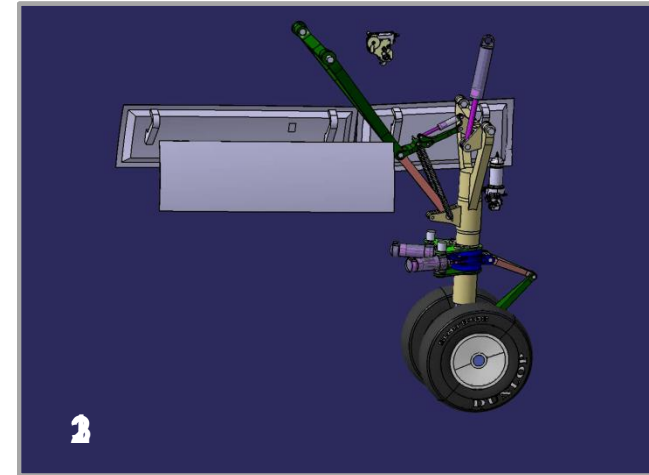
Liebherr-Aerospace site in Lindenberg

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Landing Gears

Landing Gear System Requirements

- n Manoeuvrability and stability during ground operation
- n Actuation system to retract the shock struts during cruise
- n Small installation space und low weight
- n Energy absorption during landing impact
- n High reliability in service and safety in Operation



Function of a Landing Gear



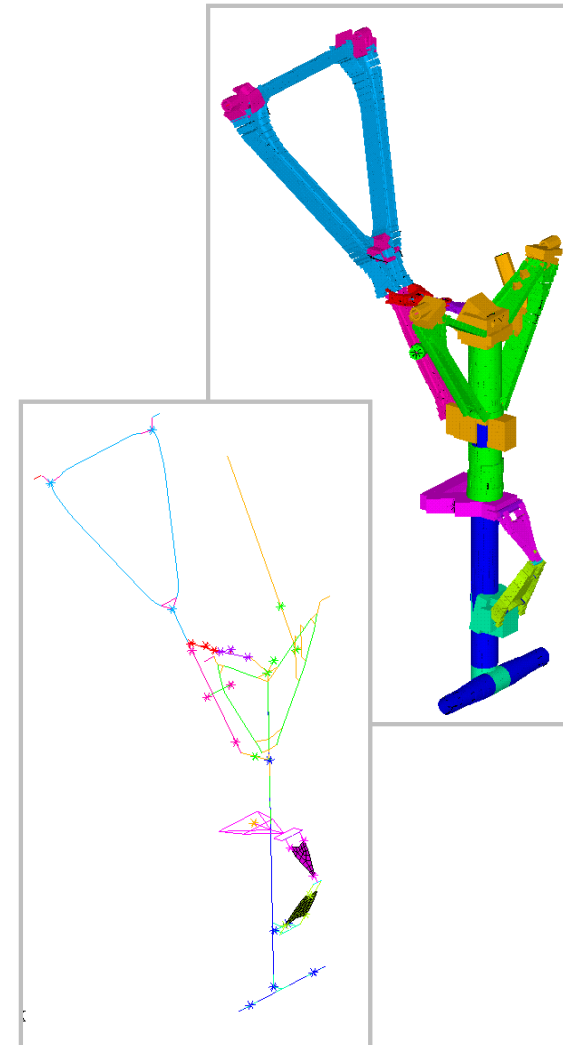
Bombardier Cseries during landing

Beam Model: Introduction

- n Beam Model is a very quick, stable and reliable tool with sufficient accuracy for section load calculation and dynamic analyses
- n Established tool in aeronautics
- n Delivered to aircraft manufacturer for Landing Gear integration

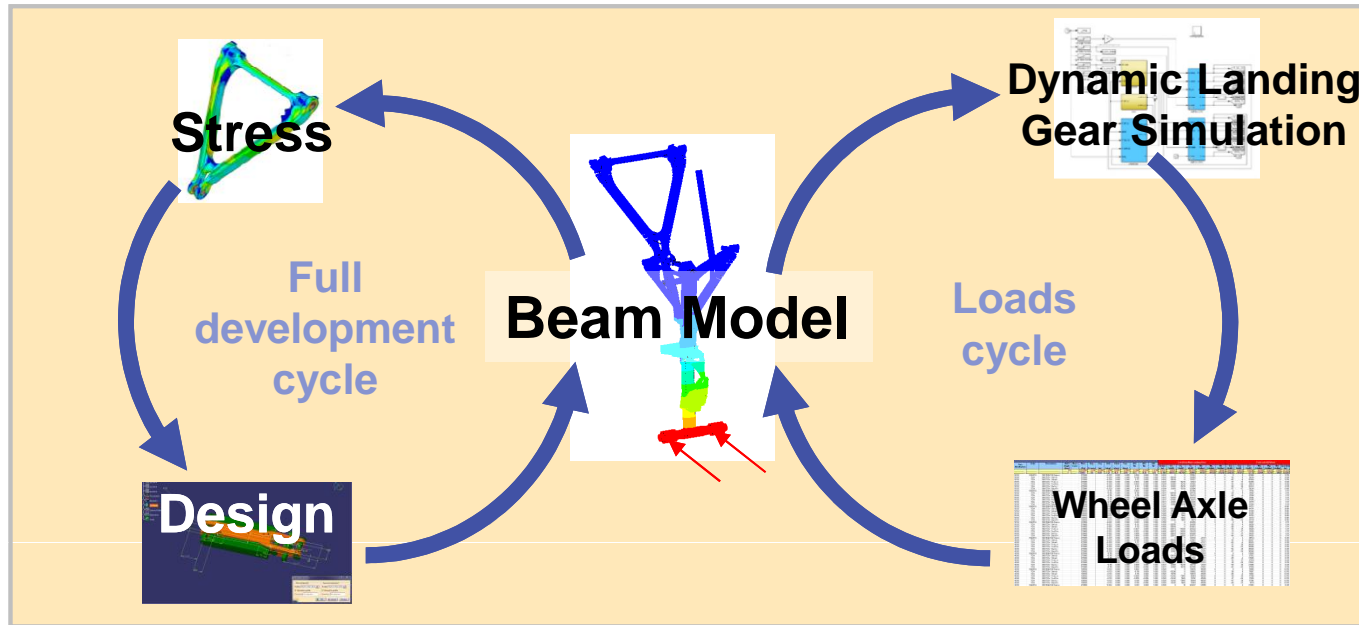
- n Less than 10^3 elements
- n Intuitive handling due to visualization of 3D beam cross sections
 - ∅ One of the major reasons why ANSYS Mechanical APDL is the tool of choice

- n Beam model matches the real Landing Gear mechanical behavior
 - ∅ Stiffness
 - ∅ Mass
 - ∅ Modal behavior
 - ∅ Load path distribution



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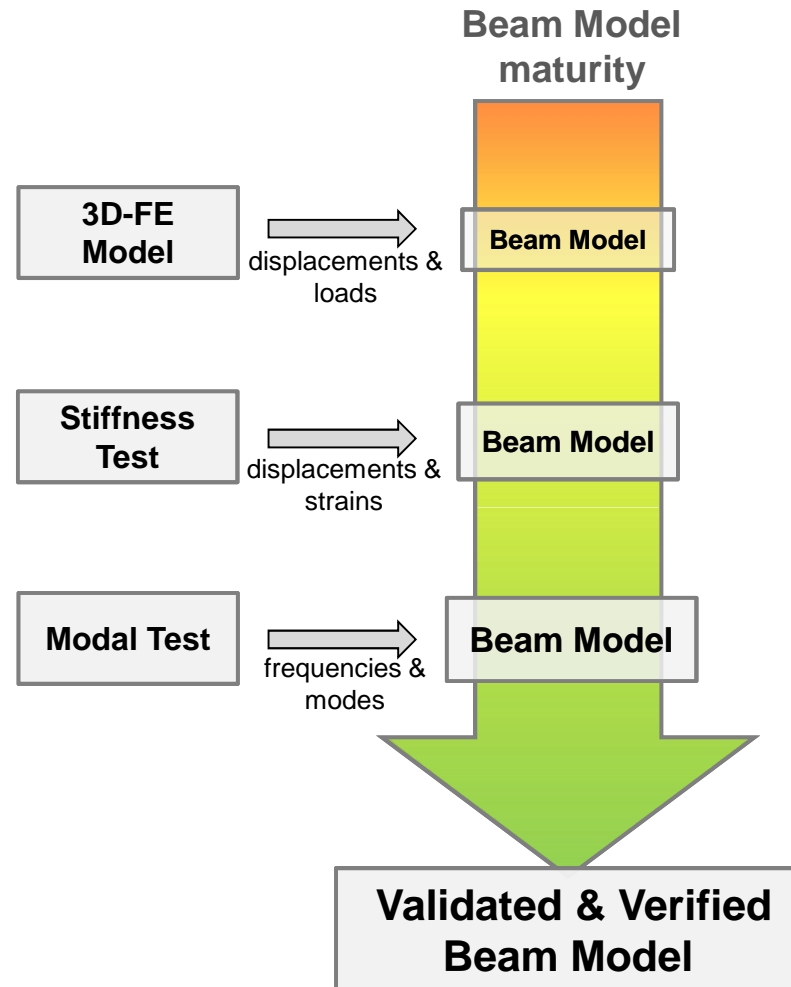
Beam Model: Utilization



- n Beam Model used for calculation of static and fatigue load cases
- n Loads extraction (section forces and moments) at defined locations for analytical or component stress calculation
- n Basis for dynamic analysis (vibration, shimmy etc.)
- n Highly automated in spite of the high number of interface points

Validation & Verification (V&V): Overview

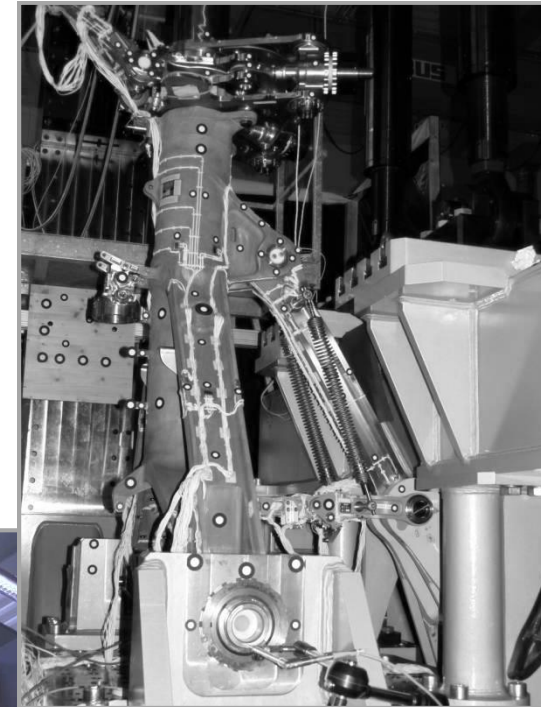
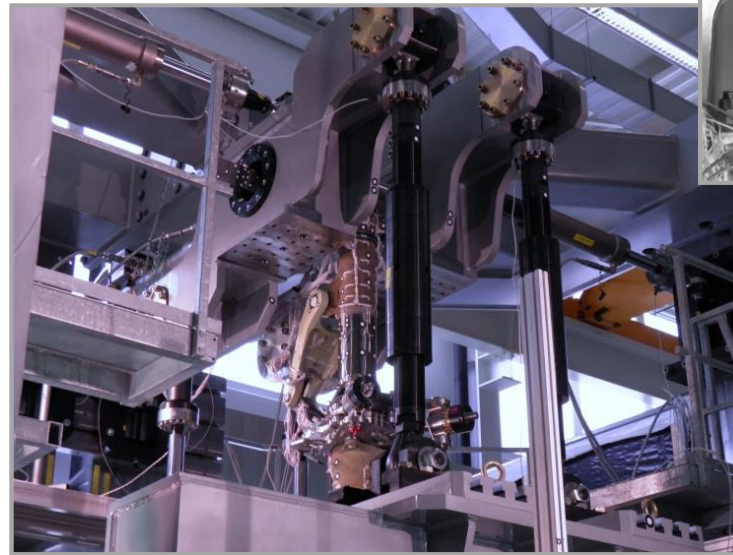
- n Due to the prominent role of the beam model, a comprehensive validation and verification is essential
- n Alignment of Beam Model and 3D-FE results is a proven and mature process
 - ∅ Can be performed at every step in development process
 - ∅ Stiffness and modal test are for validation purposes but prevalently do not lead to modifications
- n The beam model can only be as precise as the data basis from test or simulation



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V&V: Stiffness Test

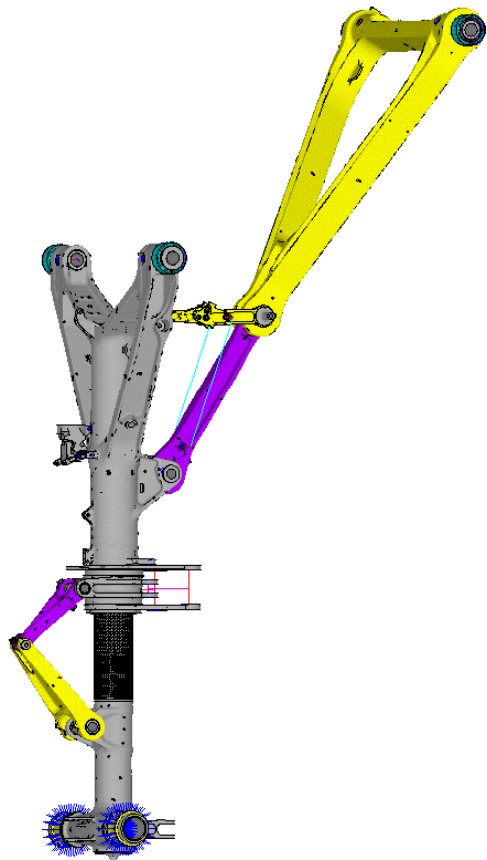
- n Different shock absorber strokes
- n Different unit load cases: fore/aft, lateral, torsional
- n Displacements recorded at about 200 locations
- n Strains recorded at hundreds positions



Strength test rig including landing gear from two perspectives

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V&V: Validation with 3D-FE Model

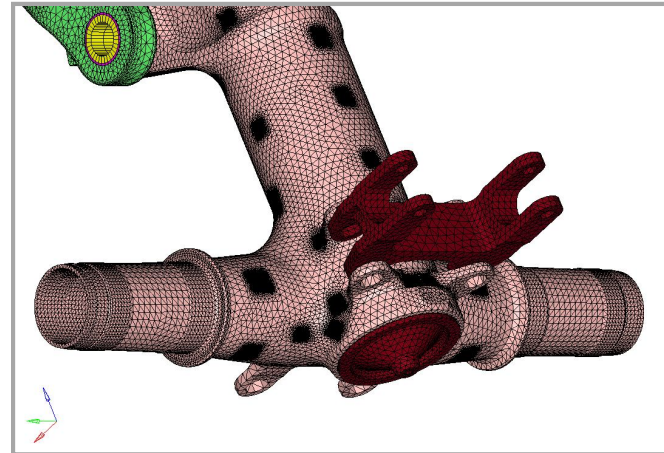


3D-FE Model

- n Nonlinear 3D-FE model with
 - ∅ $12 \cdot 10^6$ DOF
 - ∅ All important structural parts included
 - ∅ Contact elements between components
 - ∅ Strain Gauges simulated in model

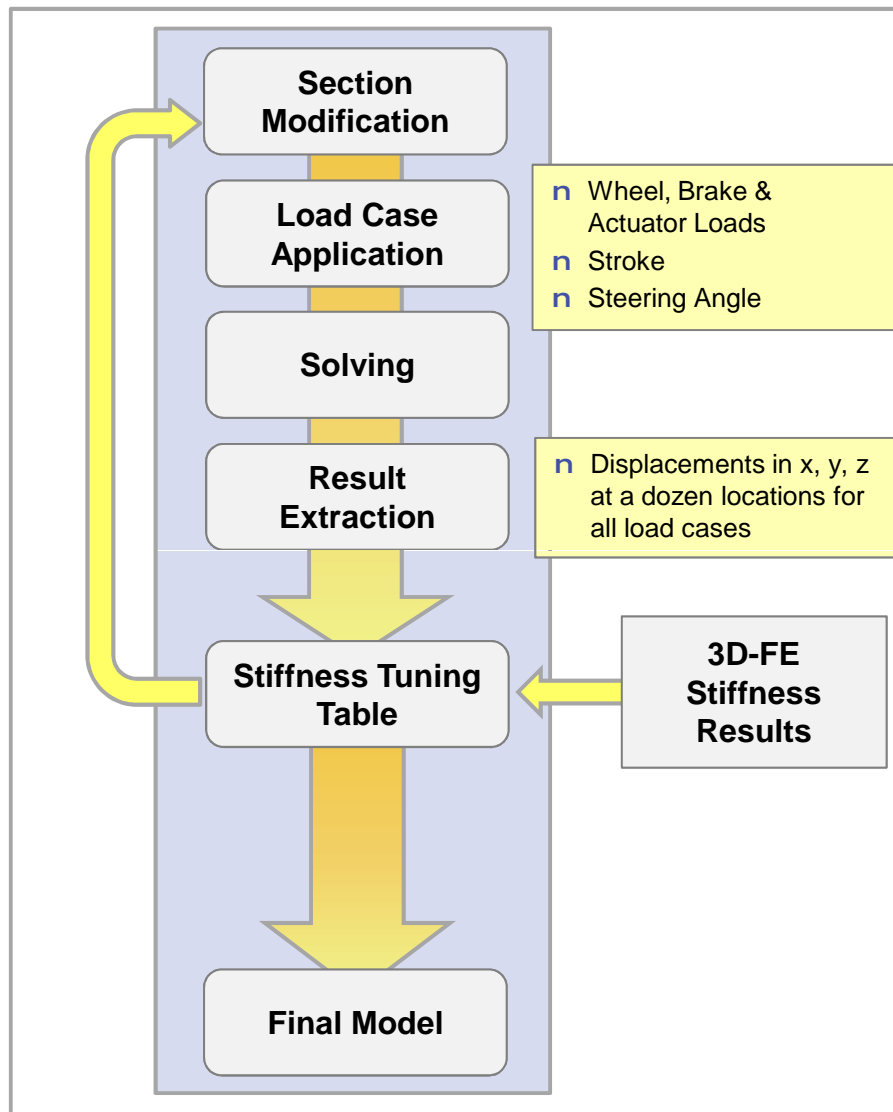
- n Load extraction at defined cross sections

- n Displacement measurement at positions defined by beam model nodes



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V&V: Stiffness Tuning

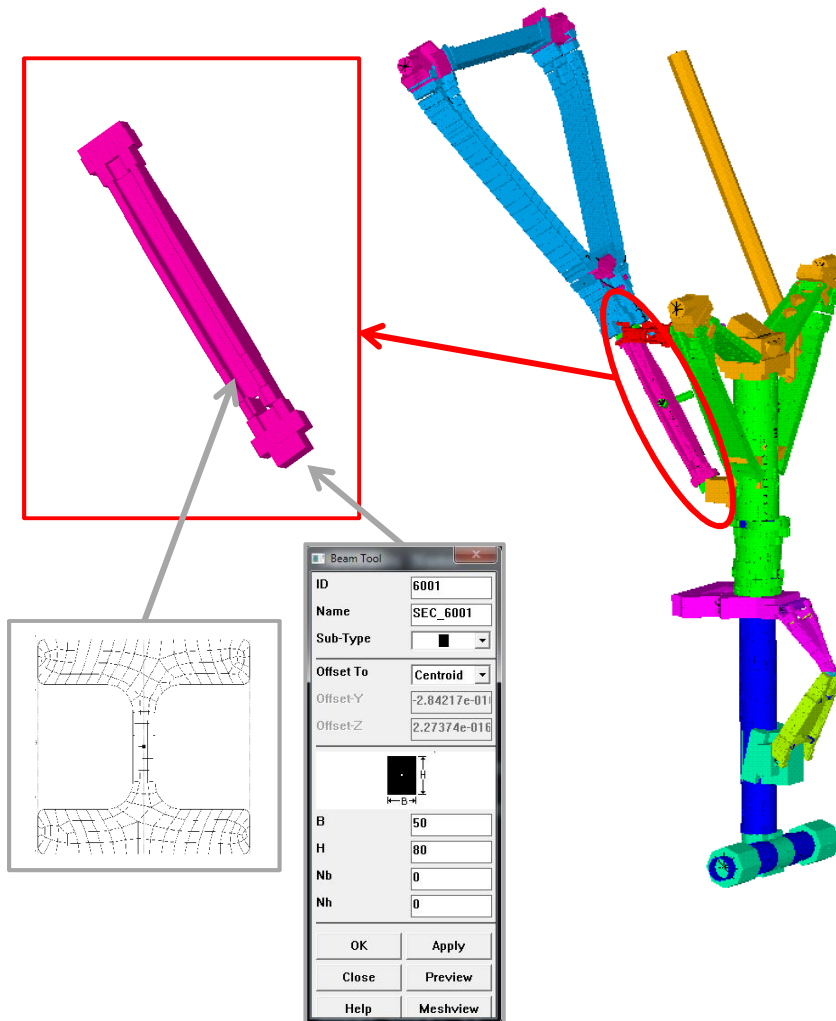


Stiffness Tuning

- n 3D-FE or test as data basis
 - ∅ Commonly validation by 3D-FE and verification through test
- n Modification of the beam model's stiffness in order to match the stiffness behavior of the real landing gear
- n Without tuning stiffness deviations may be unreasonable high
- n A proper stiffness basis is required: Either from a test or a 3D-FE model

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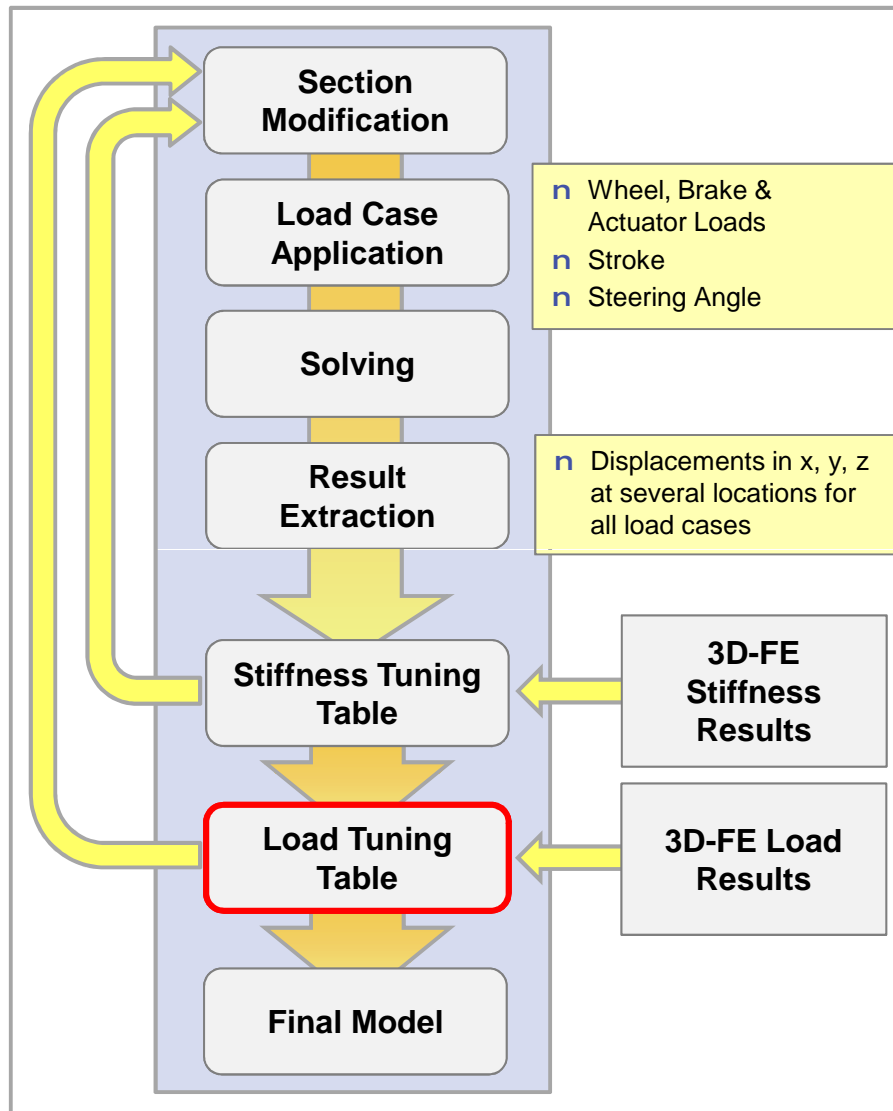
V&V: Stiffness Tuning (2)



- n Stiffness Tuning process
 - ∅ Modify section dimensions until a specific target displacement value is reached
 - ∅ Check influence on displacements of different strokes and load cases
- n APDL scripts available and utilized for Preprocessing, Solving and Postprocessing
- n Fully automated optimization has been established

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V&V: Load Tuning



Load Tuning

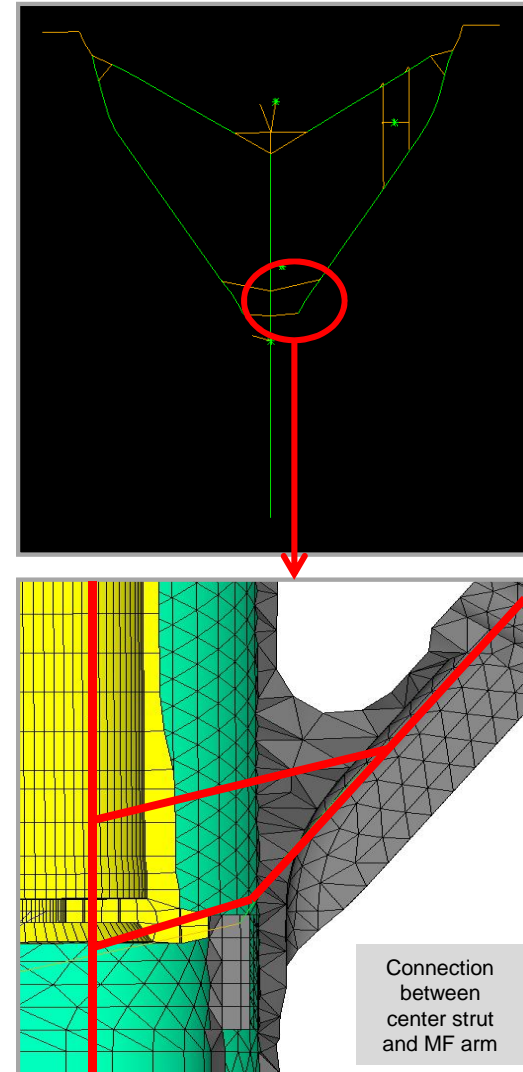
- n Modification of the beam model's stiffness in order to match the load distribution of the real landing gear
- n Load tuning is optional because the stiffness tuning provides an adequate accuracy
- n Load tuning improves the accuracy of load path distribution which is the main purpose of the beam model
- n A load basis for a load tuning can only be delivered by 3D-FE model

V&V: Load Tuning (2)

- n Load tuning performed by modifying connections between substructures
- n Individual section modification at each connection essential for load distribution
- n However, the overall stiffness shall not be changed.

- Criteria for load comparison and assessment developed:

- Only loads of considerable magnitude compared
- $\frac{F_i}{F_{res}} > 60\%$; $\frac{M_i}{M_{res}} > 60\%$
- ...

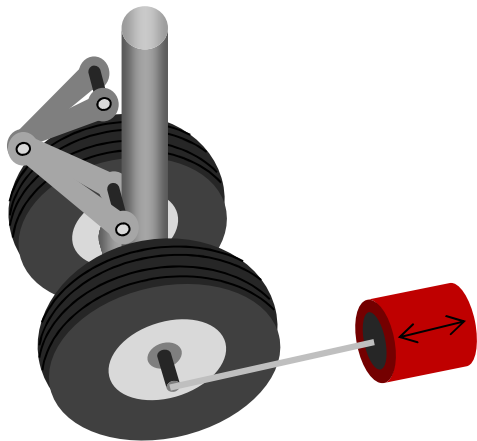


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V&V: Modal Test & Tuning

Modal Test

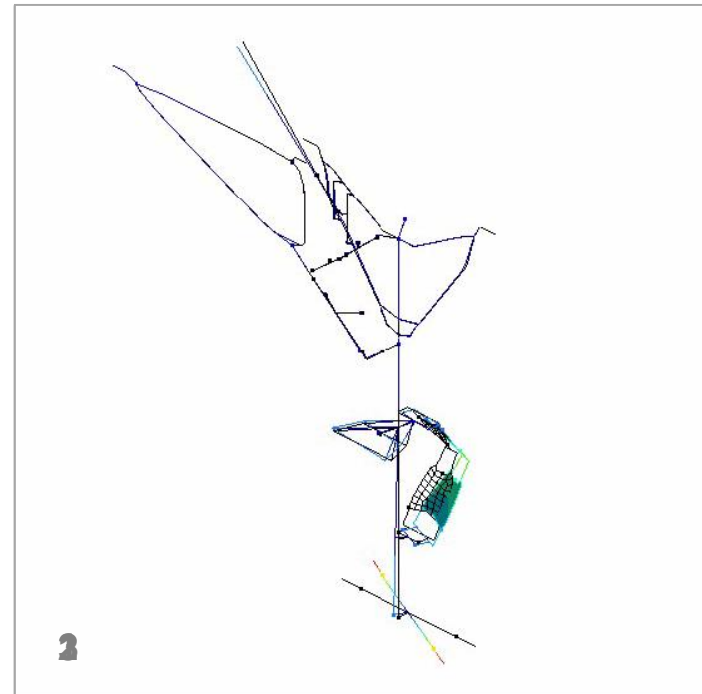
- n Landing gear attached to aircraft prototype structure (aircraft on jacks)
- n Landing gear fully equipped (wheels, hydraulic equipment and supply...)
- n Load introduction at wheel axle in different directions
- n Mode, frequency and damping is measured



Setup of modal test

Modal Analysis

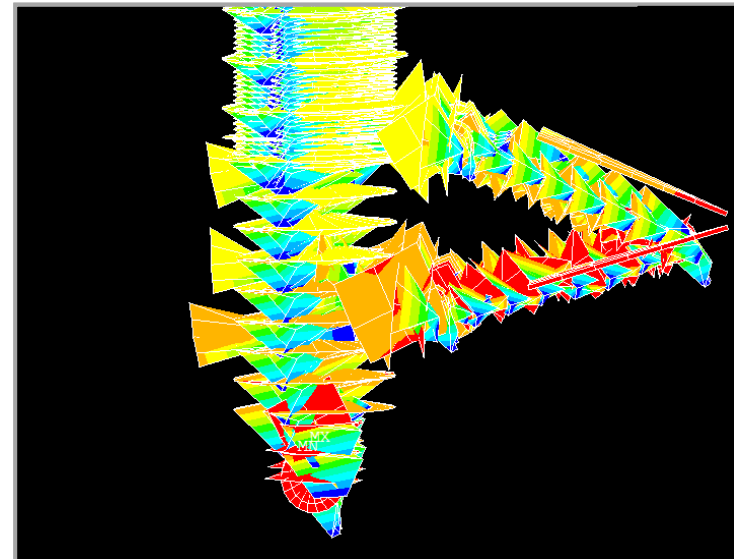
- n Beam Model attached to aircraft stiffness matrix (superelement)
- n Hydraulic steering stiffness considered



Typical Landing Gear mode shapes

Summary

- n Beam Model is central tool in load calculation process during landing gear development
- n Efficient due to small size, but resembles mass, stiffness and load distribution
- n Beam Model is adapted to 3D-FE model in order to reach sufficient accuracy
 - ∅ Adaption process inevitable in order to reach sufficient accuracy
 - ∅ Stiffness Tuning
 - ∅ Load Tuning
- n Several tests performed in order to verify the Beam Model



Miscarried Beam Model result displacement plot

Thank you for your attention

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