Simulation of Ground Operations in Aircraft Design

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Motivation for Simulation of Aircraft Ground Dynamics

- Rigid body oscillations
- Structural strength
- Dynamic loads on LG
- Structural vibrations
- Landing gear vibrations
Applications of Multibody Simulation as a “Virtual Testbed”

- Applications in aircraft ground dynamics
  - landing impact: dynamic ground loads
  - landing impact: dynamic behaviour of overall system
  - ground run: resonance effects, vibrations
  - cornering: dynamic loads
  - brake-gear interaction
  - soft-soil operations
  - landing gear positioning, kinematics
  - evaluation of new concepts
  - etc…
Trends in Aircraft and Landing Gear Design

Enhancement of simulation capabilities, esp. in respect to:
- Aircraft tyre properties (high and low speed)
- Aerodynamic effects (steady and dynamic)

“For aerodynamic aspects of takeoff and landing flight dynamics, current analysis capabilities are not sufficient to detect and avoid undesirable dynamic characteristics. […] It is important that sufficiently accurate techniques be applied to predict dynamic characteristics from the beginning of the design effort.”

Committee on Aeronautical Technologies of the Aeronautics and Space Engineering Board, in: Aeronautical Technologies for the Twenty-First Century
Aerodynamics in Aircraft Ground Dynamics: Why…?

Problems of the standard approach of modelling and simulation
Modelling derives from FAR 25 certification requirements:
„lift = weight“ \(\Rightarrow\) NWW (Newton-was-wrong) approach

- Complex landing sequences are not realistically modelled.
- Airframe deformation at impact starts from the undeformed 0g-state, not from the pre-stressed +1g-state.
- Wing deformation (bending, torsion) causes aerodynamic effects which influence dynamic behavior and loads.
- Pilot / FCS inputs cannot be modeled.
- Ground effect is being neglected.
Aerodynamics in Aircraft Ground Dynamics: How…?

Standard approach of MBS
- Force elements and sensor at marker frames of the flexible MBS body

…but:
- CPU time „explodes“
- a lot of work to set up the model
- much more work to modify the model in trade-off studies or optimizations
Aerodynamics in Aircraft Ground Dynamics: What…?

Requirements of „MBS Aerodynamics of the Flexible, Maneuvering A/C“

- Quick and simple modeling:
  - „computer-aided“ model set-up
  - use of existing disciplinary modeling
- Easy to modify if design changes
- Efficient computation of the job
- Adequate representation of high-lift aerodynamics
- Pilot controlled 3D-maneuvers
- Aerodynamic effects of structural deformation:
  - state-dependent
  - velocity-dependent
Integrated Design Process of Aircraft Ground Dynamics

- **FEA model**
- **stress / strain**
- **modal data**
- **dyn. loads**
- **AeroFEMBS**
  - airloads
  - SID file
- **CFD**
  - CFD model
- **LOADS**
  - SOD file
- **SIMPACK**
  - MBS model
  - MBS results
Aeroelastic Preprocessing

**Step A**
- CAx Models
- Seizes CAx models, correlates mCSM, CFD grids
- Fluid-structure coupling

**Step B**
- Defines and analyses reference configuration
- Rigid body reference aerodyn.

**Step C**
- Selects and analyses relevant rigid body modes
- Rigid body attitude & motion

**Step D**
- Selects and analyses rel. control surface deflections
- Control inputs

**Step E**
- Selects and analyses rel. deformation modes
- Elastic deformation

**Step F**
- Selects approximation method, analyses at sampling points
- Ground effect

**SIMPACK Input File**
Example: Landing of a Large Transport Aircraft

- Model: large transport aircraft (basing on A340-300)
- Scenario: hard touch-down, low wing
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![Graphs showing position and velocity of A/C reference frame](image)
Example: Landing of a Large Transport Aircraft

- **Model:** large transport aircraft (basing on A340-300)
- **Scenario:** hard touch-down, low wing

![Graphs showing load on left and right MLG (mainfitting)](image)

- **Load on left MLG (mainfitting):**
  - Time [s]
  - Load [N]
  - Lines represent different cases:
    - A-RG
    - A-EG
    - A-EA

- **Load on right MLG (mainfitting):**
  - Time [s]
  - Load [N]
  - Lines represent different cases:
    - A-RG
    - A-EG
    - A-EA
Example: Landing of a Large Transport Aircraft

- **Model:** large transport aircraft (basing on A340-300)
- **Scenario:** lift dumper deployment at rebound

![Graphs showing stroke of left MLG and load on left MLG](image)
## Computational Advantage of Aeroelastic Preprocessing

**SIMPACK-Simulation of Aircraft Landing Sequence**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>CPU Time</th>
<th>CPU Time Penalty</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0g-state</td>
<td>Force Elements</td>
</tr>
<tr>
<td>A FAR 25.481 (high AoA)</td>
<td>111.8 s</td>
<td>526.4 s</td>
</tr>
<tr>
<td>B FAR 25.479 (3-point)</td>
<td>81.8 s</td>
<td>447.0 s</td>
</tr>
<tr>
<td>C Left wing low (5.7°)</td>
<td>117.3 s</td>
<td>625.8 s</td>
</tr>
<tr>
<td>D Lift dumpers deployed</td>
<td>-</td>
<td>599.5 s</td>
</tr>
</tbody>
</table>
Summary

- Thorough investigation of aircraft ground dynamics is important in aircraft design.
- Multibody simulation is a valuable software tool throughout the development process... from conceptual design to certification.
- SIMPACK can be efficiently employed in aircraft design – in its standard version, and even more so in customised „derivatives“.
- Analysis results indicate that aerodynamic effects play an important role in aircraft ground dynamics.
- Simulation of the elastic, free-flying, manoeuvring aircraft can be fast, straightforward and easy-to-perform in an integrated design process.
- Comprehensive simulation of a new design entails acceptable penalties, especially when compared to the potential gain.