Full Vehicle Durability Prediction Using Co-simulation Between Implicit & Explicit Finite Element Solvers

SIMULIA Great Lakes Regional User Meeting

Oct 12, 2011

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Overview

Motivation

Co-simulation
- Vehicle Model
  - Body
  - Suspension
  - Tires
- Validation
- Use cases

Suspension template modeling in Abaqus/CAE
- K&C, Vibration, Durability
- Use cases

Summary
Motivation

Vehicle Durability Workflow

Bench Test

Road Loads

Component Loads and Stresses

Fatigue Life Prediction
Motivation

• Simulation can provide detailed insight into the vehicle behavior early in the design cycle before physical prototypes are available.

• Accurate and efficient simulation of vehicles on test track requires a broad range of functionality, like:
  - Mechanisms
  - Substructures (Linear)
  - Plasticity and Failure
  - Contact

• High performance computing – Complex system level models, faster turnaround
Co-Simulation

• Implicit vs. Explicit analysis for full vehicle durability

Implicit
• “Large” time increments; each is relatively expensive
• Period of interest is long relative to vibration frequency
• Linear response
  – Substructures
• Smooth nonlinear response

Explicit
• “Small” time increments; each is inexpensive
• High-speed dynamics
• Discontinuous nonlinear behavior
  – Impact
  – Material failure
Co-simulation

- Identify the regions suited for Implicit and Explicit solution techniques
- Vehicle Body and Suspension solved using Implicit solution scheme in Abaqus/Standard
  - System of equations solved using HHT time integration
- Explicit solution scheme for Tire-road interaction
  - Rapid changes in contact state and impact handled by the general contact algorithm in Abaqus/Explicit
- The two parts are solved independently
- Individual solutions are coupled together to ensure continuity of the global solution across the interface
Vehicle Model

- Substructures provide an efficient way to model the linear response of the body for long duration events
  - Enhanced dynamic response with Fixed interface modes, Free interface modes or Mixed

- High performance computing enables full Body meshes with elastic-plastic materials to be used in short duration impact events where significant plastic strains are expected
Vehicle Model

- Kinematic joints and bushings in the suspension and steering subsystems modeled using 12 DOF connector elements
  - Coupled behavior between various DOFs possible
  - Bushing connectors calibrated using physical test data or detailed finite element models
  - Friction, plasticity, damage and failure can be prescribed for the connector elements

- Suspension components modeled as rigid, substructure or non-linear deformable depending of the level of fidelity sought from the simulation
Tire Model

Requirements:
- Accurate representation of spindle forces and moments
- Impact with short wavelength obstacles
- Ease of calibration: Fewer physical tests
- Fast turnaround

Advantage of Finite Element tire models:
- Relative ease of calibration
  - Coupon tests to determine cord material properties
  - Continuous calibration not necessary
Validation

Co-simulation results validated against a standalone Abaqus/Explicit simulation

- Vehicle travels over a bump 160 mm X 80 mm
- Body and suspension components assumed rigid for simplicity and faster turnaround
- Results compared at the wheel centers as well as the reference nodes of rigid bodies (control arm)
- Subcycling ratio close to 300
Validation

Inflation and Gravity loading using quasi-static Implicit followed by Implicit-Explicit co-simulation

- Import the tires into Abaqus/Explicit from the gravity loaded configuration
- Co-simulation between the models for pothole impact, fatigue reference road, etc.

Gravity settling in Abaqus/Standard using quasi-static implicit

Implicit dynamics in Abaqus/Standard

Explicit dynamics in Abaqus/Explicit

Co-simulation
Validation

Left Wheel center

Comparison between Implicit-Explicit co-simulation and Standalone Explicit simulation at the left wheel centre.
(a) Longitudinal acceleration (b) Vertical acceleration (c) Vertical velocity (d) Vertical displacement
Validation

Right control arm center of gravity

Comparison between Implicit-Explicit co-simulation and Standalone Explicit simulation at the centre of gravity of the right lower control arm. (a) Longitudinal acceleration (b) Vertical acceleration (c) Vertical velocity (d) Vertical displacement
Use Cases: Curb Impact

- Stationary vehicle being impacted by a moving pendulum
  - Quasi-static gravity settling and steering maneuvering performed in Abaqus/Standard
  - Assess damage to the suspension and steering system components
    - Onset of plasticity expected in suspension components
  - Body modeled as a substructure
  - Event duration is very short (~50 ms)
Use Cases: Pothole Impact

- Vehicle traveling at 30 km/h runs into a pothole
  - Onset of plasticity expected in parts of the Body
  - Elastic-Plastic material used for the entire Body
  - Event duration is moderately long (~500 ms)
Use Cases: Fatigue Reference Roads

- Vehicle travels over roads paved with Belgian blocks
  - Event duration is long (~50s)
  - Obtain road load data
  - Body and suspension components modeled using substructures
Template-based Suspension Modeling in Abaqus
Template-based Suspension Modeling

Automotive Vehicle Suspension

Front Double Wishbone Type

Rear Leaf Spring Type
Suspension modeling in Abaqus

Unified CAE Analyses for Automotive Vehicle Suspension: kinematics & compliance, vibration, and durability

http://www.ncac.gwu.edu/vml/models.html
Abaqus/CAE Plug-in for suspension modeling
Abaqus/CAE Plug-in for suspension modeling

- Rigid Part -> Flexible Part
Abaqus/CAE Plug-in for suspension modeling

Kinematics and Compliance Analysis

Vehicle Suspension Analyzer

Simulation Tool

Simulation Type: Kinematics and Compliance

- Kinematics and Compliance
- Vibration (Steady State Dynamics)
- Durability (Implicit Dynamics)

Simulation Data:

- Front Bump Stroke: 80
- Front Rebound Stroke: 80
- Rear Bump Stroke: 80
- Rear Rebound Stroke: 80
- Longitudinal Max Force: 1000
- Lateral Max Force: 1000
- Front LH Vertical Force: 2975
- Front RH Vertical Force: 2975
- Rear LH Vertical Force: 1227
- Rear RH Vertical Force: 1227

Steering Wheel Full Rotation (Deg): 400

- Field Output
- General History Output

History Output:

- Up Contact Force
- Wheel Center
- Damper
- Spring
- Stepper

Job Name:

Job Name: KC_RB

Graphs:

- Front LH Toe (Double Bump)
- Front LH Wheel Center X Displacement (Longitudinal Compliance)
- Wheel Tip Z Displacement (mm)
- Front LH Wheel Rate (Double Bump)
- Wheel Bump (Nm)
- Wheel Tip Z Displacement (mm)
# Abaqus/CAE Plug-in for suspension modeling

## Vibration Analysis

**Vehicle Suspension Analyzer**

<table>
<thead>
<tr>
<th>Simulation Tool</th>
<th>Simulation Type</th>
<th>Rigid Model</th>
<th>Partly Flexible Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vibration (Steady State)</td>
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<tr>
<td>Kinematics and Compliance</td>
<td>Vibration (Steady State)</td>
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<td>Rear Tire Radial Stiffness</td>
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<tr>
<td>Rear Tire Radial Damping</td>
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<tr>
<td>No Tire Damping</td>
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<td>Quicker</td>
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<td>Output Set-up</td>
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<td>General History Output</td>
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<td></td>
<td>Steering System</td>
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<td>Frequency Extraction Parameter</td>
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<td>Max. Freq (Hz)</td>
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<tr>
<td>Tire Vertical Force in All Frequency Range</td>
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<tr>
<td>Front LH Tire</td>
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<tr>
<td></td>
<td>Imaginary</td>
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<tr>
<td>Front RH Tire</td>
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<td>Rear LH Tire</td>
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**Graphs**

- **Velocity** vs **Frequency**
  - V1 Damper Top LH Flexible Lower Arm
  - V1 Damper Top LH Rigid Lower Arm
Abaqus/CAE Plug-in for suspension modeling

Implicit Dynamics

![Vehicle Suspension Analyzer](image1.png)

- **Simulation Tool**
  - Simulation Type: Durability I (Implicit Dynamics)
  - Kinematics and Compliance: Vibration (Steady-State Dynamics)
  - Front Tire Radial Stiffness: 200
  - Rear Tire Radial Stiffness: 150
  - Front Tire Radial Damping: 59
  - Rear Tire Radial Damping: 59
  - Gravity
  - Output Set-up: Field Output, General/History Output, Steering System
  - Implicit Dynamic: 3g Connector Load Type: Displacement
  - Total Time: 1, Time Step: 0.01
  - Apply Force at FL LH, Magnitude: 1, History: FL_LH_force_load
  - Apply Force at FR RH, Magnitude: 1, History: FR_RH_force_load

![Displacement vs Time](image2.png)

- **Rigid Model**
- **Partly Flexible Model**
Case Study: Truck Suspension

- Vehicle BODY
- Body Mount
- FRAME
- FRONT SUS
  - Double Wishbone
- REAR SUS
  - Leaf Spring

http://www.ncac.gwu.edu/vml/models.html
Case Study: Truck Suspension

In model, *TIE is used assuming very small relative movement.

1. REBOUND CLIP (*coupling*)
2. U-BOLT
3. Center Bolt (ignore in model)
4. Fish Plate
5. Dummy Part
6. AXLE
7. Pre-tension

©Dassault Systèmes | SGL Michigan RUM, October 12, 2011
Case Study: Flexible Frame + Suspension forms

Vehicle Suspension Builder
Case Study: Vibration Analysis

- Frequency: ~ 1 Hz
- Frequency: ~ 43 Hz
Case Study: Durability

Durability (Implicit Dynamics)
**Summary**

**Co-simulation:**
- A co-simulation technique combining the strengths of both implicit and explicit solution techniques is implemented in Abaqus
  - The methodology allows the implicit simulation to take time steps that are orders of magnitude larger than the explicit time increments, without loss of accuracy
- The results obtained using the co-simulation methodology for a full vehicle simulation matches very well with those from a standalone explicit dynamic simulation
- The schemes offers a powerful tool for full vehicle durability simulations
- Rapid increase in compute power accessible to engineers is driving the shift towards high fidelity system level simulation

**Template-based suspension modeling**
- Plug-in available for efficient building up certain suspension models
- Leverages Abaqus functionality for easy to set up of K&C, Vibration and Durability analyses
LOGICAL AND PHYSICAL SIMULATION

ABS example: Abaqus-Dymola co-simulation

Sophisticated hydraulics/state machine