Virtual Road Load Data Acquisition with MSC.ADAMS/Car

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Overview

- Fatigue life prediction process
- Virtual Road Load Data Acquisition (VRLDA)
  - Virtual Proving Ground
    - Road measurement
    - Road and path generation
  - Full vehicle MSC.ADAMS/Car model
    - Modelling details
    - MSC.ADAMS/FTire
    - MSC.ADAMS/SmartDriver
- Analysis and validation of results
  - Belgian Block Wave Section
  - Hill section

- Summary
Virtual Fatigue Life Prediction – Step A and Step B

**Real World**
- **Vehicle (Mule & HW Phases)**: Road Load Data Acquisition
- **Wheel Center Load Test Data**

**Lab**
- **Component / Subsystem Fatigue Test Rig**
- **Test Rig Drive Signal Generation**

**Road**
- **Prototype Durability Test**
- **Real Fatigue Life**

**Virtual World**
- **Step B**
  - **Quasistatic Model**
    - **Math: Start with 1st Dev Phase**
  - **Max. Loads**
  - **Static FE-Analysis**
  - **Validation Experience**
  - **Fatigue Life Estimation Stress Target**
Virtual Fatigue Life Prediction – Step C

**Road**
- Vehicle (Mule & HW Phases) Road Load Data Acquisition
- Wheel Center Load Test Data

**Lab**
- Component / Subsystem Fatigue Test Rig
- Test Rig Drive Signal Generation

**Road**
- Prototype Durability Test
- Real Fatigue Life

**Real World**

**Virtual World**

**Virtual** Test Vehicle (Mule & HW Phases) Load Data Calc.

**Step C**
- Component Road Data Generation
- Component Fatigue Simulation
- Fatigue Life Prediction (Simulation)
Virtual Fatigue Life Prediction – Step D: VRLDA

**Lab**
- Component / Subsystem
- Fatigue Test Rig

**Road**
- Prototype
- Durability Test

**Real World**
- Validation Only

**Virtual World**
- Virtual Test Vehicle (Mule & HW Phases)
- Load Data Calc.

**Virtual Road & Driver**
- Virtual Test Vehicle
- Drive Signal Generation

**Virtual Test Rig**
- Component Fatigue Simulation

**Fatigue Life Prediction (Simulation)**

**Step D**
- Virtual Test Rig
- Drive Signal Generation

- Component Data
- Real Fatigue Life
Fatigue life prediction based on VRLDA

Localization of crack initiation areas:
- Sheet metals
- Spot welds
- Seam welds
- Solids

Calculation of life time in critical areas

Load Time Histories

Fatigue Analysis

Fatigue FE Model
Course Dudenhofen and Durability Programs

Durability Programs:

**G0:**
- Belgian block wave section
- Durability track with hill section
- Potholes and ramps
- Ride track

**E0, SD1:**
- Torture tracks
- Durability track with hill section
- Potholes and ramps

**P3:**
- Short program for body fatigue
- Belgian block wave section (straight, \( v = 25\text{km/h} \))

Torture Tracks (Sinus Road, Belgian Block Wave Section, Hump Track etc.)

Durability Track

Hill Section

Ride Track

High Speed Track
GPS-Gyrosystem Measurement or the course

Measurement of durability track, ride track, and hill section by means of a combination of DGPS and gyro systems (sampling rate < 10 cm)

course: x,y-coordinates

height profile durability track
Proving ground: Rough roads

- Shortcut (potholes)
- Belgian blocks (durability track)
- Hill section (Turracher Höhe)
- Belgian block wave section
- Belgian blocks (Rheinstrasse)
Tire model

Fz-Force comparison of simulation and measurement

<table>
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<th>Project</th>
<th>tire</th>
<th>wheel</th>
<th>inflation pressure (kPa)</th>
<th>brand</th>
<th>type</th>
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<td>3200</td>
<td>215/55 R16 93V</td>
<td>6.5x16</td>
<td>250</td>
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<td>Turanza ER30</td>
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<td>215/50 R17 95W</td>
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<td>Eagle NCT5</td>
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<tr>
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<td>7.25x18</td>
<td>290</td>
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<td>P6000</td>
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<tr>
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<td>175/70 R14 84T</td>
<td>5.5x14</td>
<td>260</td>
<td>Firestone</td>
<td>F-580</td>
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</tbody>
</table>

Measured tires
**Tire model**

- flexible ring of belt elements,
- tire patches with contact elements,
- linkages of springs and dampers
  between rig, ring and patches

Measurement of FTire parameters
by the University of Karlsruhe:
- tire and rim dimensions and mass
- tread depth and
  - rubber high over steel belt
- inflation pressures
- inflated max. radius
- rubber properties
- ...
  transformation of F-Tire parameters into F-Tire
data-set for ADAMS/Car by COSIN (Prof. Gipser)
Road Roughness Measurement

• topometric method:

  3d information by triangulation using phase information of structured lighting and pixel coordinates

  method resolution 5 x 5 mm

• example results:

  digitized Turracher Höhe  digitized Belgian Block Wave Section
Road and Path Generation

- Building centerline path from GPS-gyrosystem measurement data with PathBuilder toolkit
- Creating smooth roads from centerline path with RoadBuilder toolkit
- Building rough roads from topometric measurement data, translate into MSC.ADAMS/FTire regular grid format
- Assembling smooth and rough roads for proving ground tracks (hill section and durability track)
- Creating potholes, washboard, chuckholes, and hump track from drawings
PathBuilder Toolkit

- Create a driver trajectory using a new energy-minimization approach
- The road becomes a constraint, a landscape where the optimization algorithm “draws” the path
- The trajectory itself is created using “internal constraints” in order to have different shapes/behaviors
- Obstacles and variable width roads can be added

Different values of the weighting factors $\alpha$ and $\beta$ shape the path differently.

Yellow: weight only curvature ($\alpha=0$, $\beta=1$)
White: some weight to tension ($\alpha=0.025$, $\beta=1$)
Red: more weight to tension ($\alpha=0.1$, $\beta=1$) shrinks the path

The energy-optimization approach of pathbuilder can efficiently adjust measured data (i.e. telemetry data), extracting a path with a smooth and continuous curvature.
RoadBuilder Toolkit

- Interactive generation of road files
- Predefined road types:
  - Oval
  - Analytic
  - Chicane
  - Measured
- 2D and 3D road generation
- Optimized curvature calculation
- Speed profile definition
- MSC-3D Road format generation
- PSD disturbance
- Variable left/right friction
- Kerbs
- Teim Orbit output file format
- Shell graphic file generation
Full vehicle MSC.ADAMS/Car model

Modelling details:

- MSC.ADAMS/Car assembly
- MSC.ADAMS/Car-Ride hydro-bushings
- MSC.ADAMS/Car-Ride freq. dep. bushings
- flexible bodies for cradle front, trailing arms, car body
- MSC.ADAMS/FTire
- MSC.ADAMS/SmartDriver
Virtual Driver Requirements

- The Virtual Durability Program at GM requires good virtual models for Vehicle, Road, Tires and Driver.

- The Virtual Driver requirements are:
  - Same inputs as real driver
    - Driving instructions from durability schedule
  - Easy to be tuned, i.e. few user parameters
    - No need to “learn” how to drive on the virtual proving ground, just go
  - Robust, i.e. able to handle difficult numerical integration problems in combination with the MSC.ADAMS/Car full vehicle model
  - “Physiological”, i.e. “sensing” the external environment and actuating vehicle channels as much as possible like a human
SmartDriver Prototype

• The Virtual Durability Program at GM requires good virtual models for Vehicle, Road, Tires and Driver

• The new MSC Driver project (SmartDriver) fits the GM requirements:
  • Same inputs as real driver: steering, throttle, brake, clutch, gear
    • Driving instructions: minimanouver data file and automatic max performance
  • Easy to be tuned, i.e. few user parameters: preview time, longitudinal shifting times
    • No learning needed
  • Robust: successfully tested on various very challenging uneven road profiles
  • “Physiological”: human parameter setting: vision, perception and actuation
SmartDriver Architecture

- SmartDriver is a feedback controller:
  - inputs: *road path, speed/acc profiles*
  - outputs: *steering, throttle, brake, clutch and gear*
- The control actions depend only on past and present measurements
- Could mimic human driving
- Drives the vehicle to its dynamic limits
- The two different control tasks are both fulfilled thanks to the reference model (*Model Based Predictive Controller*)
- Robustness and, consequently, limited need of tuning is the crucial requirement

\[\text{User Inputs:}\]
- driving style
- driving task

\[\text{SmartDriver on line learning}\]

\[\text{Task Planner}\]

\[\text{Trajectory Planner}\]

\[\text{Motion Controller}\]

\[\text{ACAR Model}\]

\[\text{Tire Model (FTire)}\]

\[\text{Road Model}\]

\[\text{Road Builder 2D 3D}\]

\[\text{Perception channels}\]

\[\text{Actuation channels}\]
The program drives the vehicle along a desired path given as a 3D curve, with a prescribed speed profile $v(s)$.

SmartDriver MACHINE controller provides inputs to the vehicle at a frequency of 100Hz.

The outer control loop computes a feasible vehicle trajectory up to the time horizon, or “preview time”, $T_p$.

SmartDriver controls the vehicle yaw rate on the “connecting” contour.

The inner control loop acts on steering, throttle and brake in order to track the yaw rate profile determined above.
SmartDriver Human Controller

- **PERCEPTION:**
  - The task of driving a car, involves mainly two types of perceptions:
  - **VISION:**
    - The “visual field” identifies the road shape and the vehicle’s position with respect to the road (*anticipatory behavior*)
    - The “optical flow” identifies the linear velocities and the differences in position, heading and instantaneous curvature, with respect to the reference trajectory (*stabilization information*)
  - **PROPRIOCEPTION:**
    - supplies informations about linear accelerations and yaw rate

- **The Driver Model reconstructs the needed informations at every instant to control the vehicle, with a physiological sampling frequency**

- **For durability type simulations, a proper driver action frequencies is essential since they could change the road loads substantially**
Results Belgian Block Wave Section: Durability Program for Body Fatigue

Vertical tire force on flat road

Vertical tire force on Belgian Block Wave Section road

Simulation reference vehicle:
Current Opel Vectra (comparable to Chevrolet Malibu)
with McPherson Front Axle and 4-Link Rear Axle
Results Belgian Block Wave Section: Durability Program for Body Fatigue

Simulation reference vehicle:
Current Opel Vectra (comparable to Chevrolet Malibu)
with McPherson Front Axle and 4-Link Rear Axle
Load Data Validation Process

Comparison (measurement/simulation) of:

- load time histories
- statistical values (min, max, mean)
- Power Spectral Densities
- Level Crossing Countings
- Relative Pseudo Damage
  (pseudo damage analysis based on a synthetic Wöhler curve with slope 5)
Results Belgian Block Wave Section: Durability Program for Body Fatigue

Rel. Damage Comparison

Green box = Max. acceptable damage range
Results Belgian Block Wave Section: Effects of different Driver Settings

Rel. Damage Comparison

Human setting:
Long. Act. Freq. = 5 Hz
Lat. Act. Freq. = 6 Hz
Results: Hill Section
Results: Hill Section Commands

```
$---------------------------------------------------------------MSC_HEADER
[MSC_HEADER]
FILE_TYPE = 'sdf'
FILE_VERSION = 7.0
FILE_FORMAT = 'ASCII'(COMMENTS)
(comment_string)
'SDF file for opel test'

$---------------------------------------------------------------MANEUVER
[MANEUVER]
INITIAL_SPEED = 13.0
INITIAL_GEAR  = 3

(MANEUVERS)
{name      abort_time  step }
'DRIVE_1'   25.0        1.0E-2
'DOWN_HILL_1'  5.0        1.0E-2
'RESTRICT_SPEED_1'  15.0    1.0E-2
'STOP_1'    4.0        1.0E-2
'DRIVE_2'   4.0        1.0E-2
'RESTRICT_SPEED_2'  8.0     1.0E-2
'DOWN_HILL_2' 12.0       1.0E-2
'DRIVE_3'   60.0       1.0E-2
'DRIVE_4'   15.0       1.0E-2

$---------------------------------------------------------------DRIVE_1
[DRIVE_1]
TASK            = 'NORMAL'
TIME_REF_MODE   = 'RELATIVE'

(STEERING)
ACTUATOR_TYPE   = 'ROTATION'
METHOD          = 'MACHINE'

(THROTTLE)
METHOD          = 'MACHINE'

(BRAKING)
METHOD          = 'MACHINE'

(GEAR)
METHOD          = 'MACHINE'

(CLUTCH)
METHOD          = 'MACHINE'

(MACHINE_CONTROL)
STEERING_CONTROL  = 'PATH'
SPEED_CONTROL    = 'MAP'

[END_CONDITIONS]
{measure       test   value      allowed_error filter_time delay_time group}
'DISTANCE'  '=='   280             1             0         0.0

$---------------------------------------------------------------SPEED_MAP_1
[SPEED_MAP_1]
MAP_TYPE = 'SPEED'

(MAP)
{ plant_s  speed }
0.0 13.0
100.0 13.0
250.0 13.0
285.0 1.5
```

---

**Component Loads**

**USA Results: Hill Section Commands**

- **MSC_HEADER**
  - **FILE_TYPE**: 'sdf'
  - **FILE_VERSION**: 7.0
  - **FILE_FORMAT**: 'ASCII'(COMMENTS)
  - **SDF file for opel test**

- **MANEUVER**
  - **INITIAL_SPEED**: 13.0
  - **INITIAL_GEAR**: 3
  - **MANEUVERS**
    - **DRIVE_1**: 25.0 seconds, 1.0E-2 step
    - **DOWN_HILL_1**: 5.0 seconds, 1.0E-2 step
    - **RESTRICT_SPEED_1**: 15.0 seconds, 1.0E-2 step
    - **STOP_1**: 4.0 seconds, 1.0E-2 step
    - **DRIVE_2**: 4.0 seconds, 1.0E-2 step
    - **RESTRICT_SPEED_2**: 8.0 seconds, 1.0E-2 step
    - **DOWN_HILL_2**: 12.0 seconds, 1.0E-2 step
    - **DRIVE_3**: 60.0 seconds, 1.0E-2 step
    - **DRIVE_4**: 15.0 seconds, 1.0E-2 step

- **DRIVE_1**
  - **TASK**: 'NORMAL'
  - **TIME_REF_MODE**: 'RELATIVE'

- **STEERING**
  - **ACTUATOR_TYPE**: 'ROTATION'
  - **METHOD**: 'MACHINE'

- **THROTTLE**
  - **METHOD**: 'MACHINE'

- **BRAKING**
  - **METHOD**: 'MACHINE'

- **GEAR**
  - **METHOD**: 'MACHINE'

- **CLUTCH**
  - **METHOD**: 'MACHINE'

- **MACHINE_CONTROL**
  - **STEERING_CONTROL**: 'PATH'
  - **SPEED_CONTROL**: 'MAP'

- **END_CONDITIONS**
  - **DISTANCE**: 280 meters, 1.0 error, 0.0 filter time, 0.0 delay time, 0.0 group

**Virtual Product Development Conference 2004**
Results: Hill Section

- Velocity (km/h)
- Measured velocity
- Simulated velocity

- Angle (deg)
- Measured steering angle
- Simulated steering angle

Path length (m)
Results: Hill Section

- Global behaviour is captured
- Need to add unevenness effect with using PSD from measurement
Summary

Yesterday

- Hardware-Driven
- CAE Supported

Today

Simulation Based Vehicle Development

Virtual vehicle fatigue development process

Enablers:
- Virtual Proving Ground
- Full vehicle MBS model
  - frequency dependent bushings
  - physical tire model
  - flexible bodies
  - realistic driver model