DASSAULT SYSTEMES

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ABAQUS 6.14

VEHICLE RIDE COMFORT AND DURABILITY SIMULATION USING ABAQUS AND FTIRE USER'S GUIDE

Abaqus User's Guide for Vehicle Ride Comfort

and Durability Simulation

Using Abaqus and FTire

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Contents

1. Introduction

The Abaqus co-simulation technique can be used to solve comfort and durability simulations of a vehicle maneuvering on an uneven road. Maneuvers such as accelerating, braking, rolling, and skidding can be modeled. The vehicle, its suspension, and wheel rims are modeled in Abaqus. The tire, the road, and the movement of the tire on the road are modeled in FTire (Flexible Ring Tire Model). Abaqus computes displacements and rotations associated with the forces and torques arising from the vehicle moving on the road, which are computed by FTire. Most of the Abaqus features are available for use, including nonlinear materials, nonlinear geometric effects, contact, and connectors. The complex tire phenomena is based on a strictly mechanical, tribological, and thermodynamical basis in FTire.

1.1 About FTire

The Flexible Ring Tire Model (FTire) is a time-domain, nonlinear tire simulation model distributed and supported by Cosin Scientific Software (www.cosin.eu). FTire is designed for ride comfort simulations, road load prediction, and durability simulation. It is suitable for road irregularities exhibiting high frequency and short wavelength excitation and provides a physically based, highly nonlinear, and dynamic tire model based on a mechanical, tribological, and thermodynamical basis. Based on structural dynamics, FTire is a spatial nonlinear in-plane and out-of-plane tire model for belt dynamics. It can capture local contact patch pressure distribution, rolling resistance, side-wall contact, large camber angles, and misuse scenarios for a frequency range up to 200 Hz, excited by short surface wavelengths, mass imbalance, nonuniformity of tire and/or rim, air cavity vibrations, and irregular tread patterns.

The FTire tire model includes capabilities to handle

- imbalances by nonhomogeneous mass and stiffness distribution, radius variation, and local tread wear;
- belt temperature distribution;
- air volume vibration;
- tire slipping on its rim for very large drive or brake torques;
- integrated flexible and/or viscoplastic rim model; and
- user-defined wear, temperature distribution, and rim flexibility models.

The FTire road/soil model includes

- full integration of the cosin/road digital road library with support for complex rigid time-invariant and time-variant road surfaces; and
- full integration of the cosin/soil digital road library with support for flexible and deformable road surfaces.

1.2 Licensing information

Co-simulation using Abaqus and FTire is an add-on analysis capability that uses the SIMULIA Co-Simulation Engine (CSE) and requires software licenses for both Abaqus and FTire. More information on licensing Abaqus can be found from the **Licensing** section of the **Support** page at www.3ds.com/simulia. For information on licensing FTire, contact Cosin Scientific Software at www.cosin.eu.

1.3 Platform support

The latest product information and platform support for the Abaqus and FTire capability can be found at www.3ds.com/support/certified-hardware/simulia-system-information/compatibility/co-simulation. In most cases Abaqus is compatible with later versions of the operating system software; however, it is usually not compatible with earlier versions. For the latest product information for FTire, see the Cosin Scientific Software homepage (www.cosin.eu).

Abaqus and FTire do not have to be run on the same platform; a coupled simulation can be performed across heterogeneous computer systems.

1.4 Setup guidelines

Before you start, you need to install the Abaqus and FTire products. For the latest information on software compatibility, see the **Co-simulation** page at www.3ds.com/support/certified-hardware/simulia-system-information/compatibility/co-simulation. It is important that you verify that each product is properly installed.

To run a co-simulation between Abaqus and FTire, the following environment variables must be defined:

Windows platforms

PATH

The path to the CTI libraries must be prepended to the **PATH** environment variable.

Linux platforms

LD_LIBRARY_PATH

Set to the path where the CTI libraries are located.

1.5 References

This section contains a list of reference material for co-simulation using Abaqus and FTire.

Abaqus

- Abaqus Analysis User's Guide
- Abaqus Keywords Reference Guide

FTire

- FTire—Flexible Ring Tire Model: Modelization and Parameter Specification (see www.cosin.eu)

1.6 Getting help

You can contact your local SIMULIA support office for technical assistance with problems. For the latest information on vehicle comfort and durability simulation using Abaqus and FTire, consult the Dassault Systèmes Knowledge Base at www.3ds.com/support/knowledge-base.

1.7 Typographical conventions

This guide adheres to a set of typographical conventions so that you can recognize actions and items. The following list illustrates each of the conventions:

- Text you enter from the keyboard: **`abaqus`**
- Hyperlinks: www.3ds.com/simulia
- Text indicating that the user has a choice: ***`filename`***

2. Solving vehicle comfort and durability simulations

This chapter provides details on how to prepare and run a vehicle comfort and durability simulation using Abaqus and FTire. The Abaqus and FTire processes communicate with each other during run time, exchanging solution fields at designated target times. The communication process is controlled by the SIMULIA Co-Simulation Engine (CSE). The following processes exist:

Abaqus

Abaqus/Standard or Abaqus/Explicit can be used to model the vehicle, its suspension, and the wheel rims. Abaqus can be run using multiple processors.

FTire

FTire models the tire, the road, and the movement of the tire on the road.

Co-Simulation Engine Director

The CSE Director process directs and controls the data exchange between Abaqus and FTire.

All three processes require input files. The Abaqus input file defines the vehicle model and must include the necessary co-simulation options, as discussed in "Preparing the Abaqus model," Section 2.1. FTire typically requires a tire file defining the tire characteristics and a road file defining the road profile. For models containing multiple tires, each tire may use a different tire and/or road files. The input to the FTire process is defined through the FTire input file, as discussed in "Preparing the FTire model," Section 2.2.

The Co-Simulation Engine Director process requires a co-simulation configuration file, which describes the co-simulation problem setup (e.g., the codes participating in the co-simulation and the fields being exchanged between the codes). The co-simulation configuration file is an XML-format file generated by the FTire process and uses information provided by the FTire input file. In most circumstances, you do not need to be concerned with the details of the co-simulation configuration file. This file is generated automatically, and the CSE Director process is started from the FTire process. Optionally, you can generate and modify the configuration file and start all of the processes manually. Typical workflows for starting the co-simulation are discussed in "Executing the co-simulation," Section 2.3.

2.1 Preparing the Abaqus model

The Abaqus input file defines the vehicle model, typically including its suspension and wheel rims. The model is typically created by a preprocessing tool. Most of the Abaqus features, including nonlinear material, large deformation and finite rotations, contact, and constraints, can be used in the model. Co-simulation with FTire is supported for the implicit transient dynamic (∗DYNAMIC) and explicit transient dynamic (∗DYNAMIC, EXPLICIT) procedures.

The vehicle is positioned as described in "Vehicle positioning relative to the road," Section 3.1. Communication of physical fields exchanged between Abaqus and FTire occurs through a point coupling representing the wheel rim in the Abaqus model. For each wheel rim, a node set with a single node needs to be defined on the *CO-SIMULATION REGION option. Abaqus computes the displacements, rotations, velocities, and rotational velocities and exports these fields to FTire. FTire computes the forces and torques, representing the loads on the rim due to the tire traveling on an irregular road, which it exports to Abaqus.

The example below illustrates the co-simulation options required for an Abaqus model that includes four tires (**Front-Left**, **Front-Right**, **Rear-Left**, and **Rear-Right**).

```
...
*NSET, NAME=Front-Left
node number for front left wheel rim
*NSET, NAME=Front-Right
node number for front right wheel rim
*NSET, NAME=Rear-Left
node number for rear left wheel rim
*NSET, NAME=Rear-Right
node number for rear right wheel rim
...
*STEP, NLGEOM
*DYNAMIC(, EXPLICIT)
...
*CO-SIMULATION, PROGRAM=MULTIPHYSICS
*CO-SIMULATION REGION, TYPE=NODE, IMPORT
Front-Left,  CF, CM
Front-Right, CF, CM
Rear-Left,   CF, CM
Rear-Right,  CF, CM
*CO-SIMULATION REGION, TYPE=NODE, EXPORT
Front-Left,  UT, UR, VT, VR
Front-Right, UT, UR, VT, VR
Rear-Left,   UT, UR, VT, VR
Rear-Right,  UT, UR, VT, VR
...
*END STEP
```

Refer to Chapter 17, "Co-simulation," of the Abaqus Analysis User's Guide, for further information about the co-simulation capability in Abaqus.

In addition, you need to define additional mass and rotary inertia properties for the rim in the Abaqus model that are not accounted for by the tire model. The additional mass and inertia properties are printed in the FTire message (**.msg**) files. An example of the printout is shown below for the **_default.tir** file provided on the FTire release media.

```
MASS AND INERTIA CORRECTION IN MBS MODEL
*either add* the following mass properties to the rim in
your suspension model ('rim-fixed' tire parts which are
not accounted for in the tire model):
  m =            3.577 kg
  Ixx = Izz =    0.115 kgm^2
  Iyy =          0.174 kgm^2  (y-axis = wheel rotation axis)

*or subtract* the following mass properties from the wheel
(=rim+tire) in your suspension model ('free' tire parts which
are accounted for in the tire model):
  m =            4.523 kg
  Ixx = Izz =    0.206 kgm^2
  Iyy =          0.412 kgm^2  (y-axis = wheel rotation axis)
```

2.2 Preparing the FTire model

The FTire model file associates each tire rim defined in the Abaqus model with a tire file that describes the tire properties and with a road file that describes the road profile. Typically, for vehicle comfort and durability simulation only one tire file and one road file are needed to describe the tire properties and the road. Under certain circumstances, different tire files (for example, when modeling a spare tire) or a different road file (for example, when modeling a pothole) may be assigned to a tire. In addition, information for vehicle placement and orientation with respect to the road may be specified in the FTire model file, in which case the vehicle is positioned relative to the road. Alternatively, the road may be positioned under the vehicle through the tire and road files; this condition is not discussed in this guide.

The information contained in the FTire model file is used to generate the Co-Simulation Engine Director configuration file, and, hence, the FTire model file also includes input related to the Abaqus solver and coupling scheme.

The FTire model file consists of data blocks that must comply with the following rules:

- Each data block is defined by the block name placed within square brackets (e.g., **[MODEL]** represents the model data block).
- One or more data lines specifying variable/value pairs may follow the block header.
- The variable and value are always separated by an equal sign (e.g., **TIRE=FRONT-RIGHT**).
- Variable/value pairs are always separated by a comma or space (e.g., **TIRE=FRONT-RIGHT, TIREFILE=_default.tir**).
- Each data block must end with an empty line.

2.2.1 [ABAQUS SOLVER] block

The **[ABAQUS SOLVER]** block defines whether Abaqus/Standard or Abaqus/Explicit is being used and specifies the Abaqus job name. In addition, this block provides information regarding the orientation of the vehicle in the Abaqus model.

JOB

Set **JOB** equal to the Abaqus job name without any file extension. The Abaqus job option may be different from the Abaqus input option used when launching Abaqus (e.g., **abaqus job**=**blowout** **input**=**car**). The job name is case sensitive.

LOCKSTEP

Set **LOCKSTEP=FALSE** (default) to allow Abaqus to take one or more increments between target times. Set **LOCKSTEP=TRUE** to force Abaqus to use a single increment to reach the next target time. Using lockstep enforces a severe condition; if Abaqus needs to cut back due to some event (e.g., contact or plasticity), it must terminate with an error because a cut back is not allowed.

SOLVER

Set **SOLVER=STANDARD** to perform an implicit transient dynamic simulation using Abaqus/Standard, or set **SOLVER=EXPLICIT** to perform an explicit transient dynamic simulation using Abaqus/Explicit. The solver variable is a required variable.

2.2.2 [MODEL] block

The **[MODEL]** block associates each rim in the Abaqus model with a tire file and a road file. It also provides information regarding the tire position normal to the road. For each tire provide a data line defining the variables listed below.

OFFSET

Set **OFFSET** equal to the distance normal to the road that the tire is initially positioned. Specify the offset distance in meters. Typically, the offset is a negative value indicating that the tire is deformed due to the weight of the vehicle. At the start of the co-simulation, FTire will perform a steady-state solution to compute the exact forces due to this offset. The default offset is 0, indicating that the tire is placed on the road.

ROADFILE

Set **ROADFILE** equal to the name of the road file that defines the road properties. The **ROADFILE** variable is a required variable. Its value is case sensitive on case-sensitive operating systems. You must provide the file extension. It is expected that the road file is located in the directory where the FTire process is started.

TIRE

Set **TIRE** equal to the node set name that defines the rim in the Abaqus model. The **TIRE** variable is a required variable, and its value is case insensitive; that is, **Front-Right** and **FRONT-RIGHT** refer to the same node set in the Abaqus model.

TIREFILE

Set **TIREFILE** equal to the name of the tire file that defines the tire properties. The **TIREFILE** variable is a required variable. Its value is case sensitive on case-sensitive operating systems. You must provide the file extension. It is expected that the tire file is located in the directory where the FTire process is started.

2.2.3 [SCENARIO] block

The **[SCENARIO]** block defines the duration of the event/scenario being modeled.

DURATION

Set **DURATION** equal to the duration of the co-simulation event being modeled. The **DURATION** variable is a required variable, and it must match the total time specified on the Abaqus procedure option.

STARTTIME

Set **STARTTIME** equal to the start time of the co-simulation event. The start time is not used currently and can be set to 0 (default).

2.2.4 [UNITS] block

Abaqus supports a consistent unit system; that is, any units can be used as long as all quantities have been defined using a consistent unit system. FTire uses the SI unit system. The **[UNITS]** block specifies unit conversion factors that convert units used in the Abaqus model to the SI unit system.

FORCE

Set **FORCE** equal to the factor to scale the force unit in Abaqus to Newtons. The default value is 1, indicating that the Abaqus model is using SI units.

LENGTH

Set **LENGTH** equal to the factor to scale the length unit in Abaqus to meters. The default value is 1, indicating that the Abaqus model is using SI units.

MASS

Set **MASS** equal to the factor to scale the mass unit in Abaqus to kilograms. The default value is 1, indicating that the Abaqus model is using SI units.

TIME

Set **TIME** equal to the factor to scale the time unit in Abaqus to seconds. The default value is 1, indicating that the Abaqus model is using SI units. The time units must always be set to 1, indicating that seconds are used, which is a current limitation.

2.2.5 [COUPLING SCHEME] block

The **[COUPLING SCHEME]** block allows you to control the coupling algorithm.

COUPLINGSCHEME

Set **COUPLINGSCHEME=GAUSS-SEIDEL** (default) to have Abaqus and FTire execute in tandem. Set **COUPLINGSCHEME=JACOBI** to have Abaqus and FTire run concurrently.

MAXEXCHANGES

Set **MAXEXCHANGES** to the number of exchanges to be performed at the coupling target time to provide a more stable solution by employing an iterative implicit coupling scheme. Set **MAXEXCHANGES=0** to select an explicit coupling scheme. The default value is 1, enabling a predictor/corrector scheme with one additional exchange at the target time. **MAXEXCHANGES** has no effect when Abaqus/Explicit is used.

2.2.6 [NEGOTIATION SCHEME] block

The **[NEGOTIATION SCHEME]** block allows you to control the synchronization method employed for establishing target times.

DT

Set **DT** equal to the time step size used when **NEGOTIATIONSCHEME=CONSTANTDT**. The default value is 1 ms.

NEGOTIATIONSCHEME

Set **NEGOTIATIONSCHEME=CONSTANTDT** to use a constant time step size defined by **DT** to establish the next target time. In this case you must specify the **DT** variable. Set **NEGOTIATIONSCHEME=ABAQUS** to have Abaqus define the target times based on its next preferred increment size.

2.2.7 Example: FTire input file

The following example illustrates the format of an FTire input file. Four tires are modeled in Abaqus with the node set labels **FL**, **FR**, **RL**, and **RR**. We assume that the rear left (**RL**) tire uses a spare whose tire properties are defined by **spare.tir** and that the remaining tires use properties defined by **oem.tir**.

A single road file (**road.rdf**) is used for all four tires. An offset of –15 mm is specified to describe the footprint due to the vehicle's weight. A Gauss-Seidel, implicit iterative scheme is selected with one additional coupling exchange per coupling step. A constant negotiation scheme with a time increment size of 0.0001 seconds is specified. The Abaqus model uses the SI unit system, and the scenario duration is 2 seconds.

```
[ABAQUS SOLVER]
SOLVER=STANDARD, JOB=Job-1, LOCKSTEP=FALSE

[MODEL]
TIRE=FL, TIREFILE=oem.tir,   ROADFILE=road.rdf, OFFSET=-0.015
TIRE=FR, TIREFILE=oem.tir,   ROADFILE=road.rdf, OFFSET=-0.015
TIRE=RL, TIREFILE=spare.tir, ROADFILE=road.rdf, OFFSET=-0.015
TIRE=RR, TIREFILE=oem.tir,   ROADFILE=road.rdf, OFFSET=-0.015

[SCENARIO]
STARTTIME=0.0, DURATION=2.0

[COUPLING SCHEME]
COUPLINGSCHEME=GAUSS-SEIDEL, MAXEXCHANGES=1

[NEGOTIATION SCHEME]
NEGOTIATIONSCHEME=CONSTANTDT, DT=0.0001

[UNITS]
LENGTH=1.0, FORCE=1.0, MASS=1.0, TIME=1.0
```

2.3 Executing the co-simulation

As discussed above, co-simulation between Abaqus and FTire runs three processes and requires input files for each process. For typical applications, the Co-Simulation Engine configuration file is created from the FTire input file automatically, and the Co-Simulation Engine Director process is launched automatically. Advanced users may need to modify the configuration file; for example, when performing *n*-code coupling between Abaqus, FTire, and additional solvers. In this case you can generate the configuration file using a datacheck and revise the file; then, all three processes must be launched manually.

This section summarizes the command line options of the FTire process and provides examples for running typical and advanced applications.

2.3.1 FTire command line options

The following options can be specified when starting FTire:

`cseconfigfile`

Option to specify the name of the Co-Simulation Engine configuration file. This option is required when the **`manualLaunch`** option is specified.

`datacheck`

Option used to perform a data check only. During a data check, the FTire model file is read and the Co-Simulation Engine configuration file is generated.

`input`

Required option to specify the name of the FTire model file. The file name, including the file extension, must be provided. The file name is case sensitive on case-sensitive operating systems. It is expected that the file is located in the directory where the FTire process is started.

`manualLaunch`

Option used to launch FTire manually. For launching manually both the **`cseconfigfile`** and **`port`** options must be provided.

`port`

Option used to specify the TCP/UDP port number for co-simulation inbound messages to the director. Set **`port`** equal to the port number used for the connection. If not specified, a random port between the range of 4000 and 6000 is selected. This option is required when the **`manualLaunch`** option is specified.

`timeout`

Option used to specify a timeout value in seconds for the co-simulation director connection. FTire terminates if it does not receive any communication from the CSE Director process during the time specified. The default value is 3600 seconds.

`verbose`

Option used to specify the verbosity level for debug output. If the level is 0 (default), no debug output is generated.

2.3.2 Example: Typical applications

This example shows the command for executing the co-simulation for most applications. You start the FTire job, which generates the Co-Simulation Engine configuration file and launches the Co-simulation

Engine Director process automatically. In this example we assume that the FTire input file is named **pothole_ftire.inp**.

To execute the co-simulation for typical applications:

1. Enter the following command to start the FTire job:

   ```
   abaqus ftire input=pothole_ftire.inp
   ```

   The Co-Simulation Engine configuration file is generated, and the Co-simulation Engine Director process is launched.
2. Start the Abaqus job using the instructions provided in the message printed to the command window.

2.3.3 Example: Advanced applications

This example shows the commands required for executing the co-simulation for advanced applications. You must generate the CSE Director process input file (Co-Simulation Engine configuration file) separately and launch the Abaqus, FTire, and the CSE Director processes manually. In this example, we assume that

- the Abaqus input file is named **vehicle_xpl.inp**,
- Abaqus is launched using two cpus,
- Abaqus/Explicit uses double precision (recommended for co-simulations),
- the CSE Director process is started on host **mercury** using port **4444**,
- the FTire input file is named **wheels_ftire.inp**, and
- the configuration file is named **wheels_ftire_config.xml**.

To execute the co-simulation for advanced applications:

1. Enter the following command to perform a data check and generate the configuration file:

   ```
   abaqus ftire input=wheels_ftire.inp datacheck
   ```

   A configuration file named **wheels_ftire_config.xml** is created.
2. Revise the configuration file as needed.
3. Launch the Abaqus, FTire, and the CSE Director processes manually.
   a. Enter the following command to start the Abaqus job:

      ```
      abaqus job=vehicle_xpl input=wheels_ftire
         csedirector=mercury:4444 cpus=2 double
      ```

   b. Enter the following command to start the FTire job:

      ```
      abaqus ftire input=wheels_ftire.inp port=4444
      ```

```
manualLaunch cseconfigfile=wheels_ftire_config.xml
```

c. Enter the following command to start the Co-Simulation Engine Director process:

```
abaqus cse job=director listenerport=4444
   configure=wheels_ftire_config.xml
```

3. Technical considerations

This section discusses some technical consideration and limitations when performing vehicle comfort and durability simulation using Abaqus and FTire.

3.1 Vehicle positioning relative to the road

The vehicle must be oriented such that the normal to the road is the positive z-axis, and the vehicle is traveling along the x-axis, as illustrated in Figure 3–1. The model shown in Figure 3–1 is created from the Taurus model in the National Crash Analysis Center (NCAC). The original finite element model has been developed by The National Crash Analysis Center (NCAC) of The George Washington University under a contract with the FHWA and the NHTSA of the US DOT. The vehicle is positioned relative to the road such that the unloaded tire radius at zero camber angle and at zero speed touches the road surface. The height can be adjusted with the **`OFFSET`** variable in the **`[MODEL]`** block of the FTire model file to provide an initial overclosure or by adjusting the road level in the FTire road file.

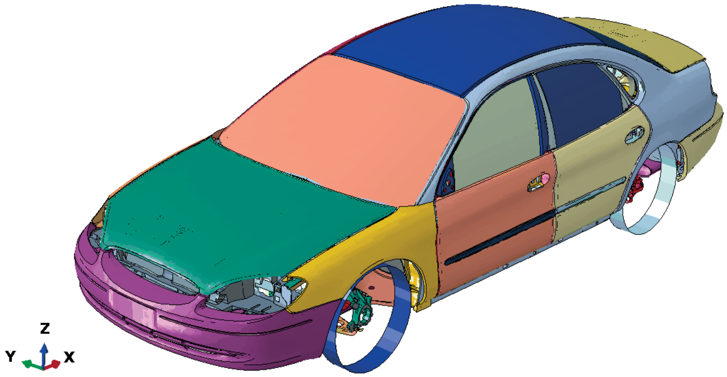

Figure 3–1 Vehicle orientation.

3.2 Units

Abaqus uses a consistent unit system; that is, any unit system may be chosen as long as all units are specified consistently in the Abaqus model. FTire uses the SI unit system. Use the **`[UNITS]`** block in the FTire input file to provide length, force, mass, and time factors to convert from Abaqus units to the SI unit system. The time units must be specified in seconds, which is a current limitation.

3.3 Precision of Abaqus simulation

To avoid numerical issues, it is highly recommended that Abaqus/Explicit use double precision.

3.4 Limitations

See the Abaqus Analysis User's Guide for general limitations regarding co-simulation. In addition to these limitations, the following limitations exist when coupling Abaqus with FTire:

- Restart analysis is not supported.
- All tires must be defined and executed in a single instance of the FTire code. Multiple FTire codes cannot be coupled with Abaqus.
- FTire co-simulation cannot be defined in more than two steps in one input file.

4. Examples using co-simulation with Abaqus and FTire

Two examples are provided for using co-simulation with Abaqus and FTire.

- "Example 1: One rolling tire on a flat road," Section 4.1
- "Example 2: Rigid vehicle model on a flat road," Section 4.2

4.1 Example 1: One rolling tire on a flat road

In this example, the model has only one tire rolling on a flat road. The wheel center is fixed except for the rolling direction and the moving direction. The initial translational and rotational velocities are assigned to the wheel center. The purpose of this analysis is to confirm that the co-simulation between Abaqus and FTire performs correctly.

In the Abaqus model, only point mass and rotary inertia are modeled. The node on the point mass and rotary inertia element are attached to FTire. In the FTire model, the default tire and flat road files in the FTire example directory are used.

4.1.1 Example 1: Files

The following files are used in this example:

- **`Abaqus_one_tire_rolling.inp`**: Abaqus input file
- **`FTire_one_tire_rolling.inp`**: FTire input file for FTire co-simulation
- **`_default.tir`**: FTire tire property input file
- **`_default.rdf`**: FTire road input file

4.1.2 Example 1: Commands

The following commands are used to run the Abaqus and FTire co-simulation:

```
abaqus job=Abaqus_one_tire_rolling csedirector=localhost:4000
   interactive
abaqus ftire input=FTire_one_tire_rolling.inp port=4000
```

4.1.3 Example 1: Validation

The validation can be done by observing the tire animation and the reaction force at the wheel center. In the example file, the total mass of the Abaqus model (wheel) is set to 10 kg. Considering CF3 and

RF3 at the wheel center, as shown in Figure 4–1, the weight of the wheel can be identified by subtracting RF3 from CF3, as shown in Figure 4–2. Output variable CF3 is the vertical force from FTire, and output variable RF3 is the vertical reaction force from Abaqus. Since CF3 from FTire considers the wheel weight and other forces affected by deflection of the tire, etc., it includes RF3 and weight of the wheel. Here, CF3 is positive since the force is acting upward due to tire deflection, and RF3 is negative since it acts in the opposite direction of CF3. In the figures below, only the absolute values of the vertical forces are considered.

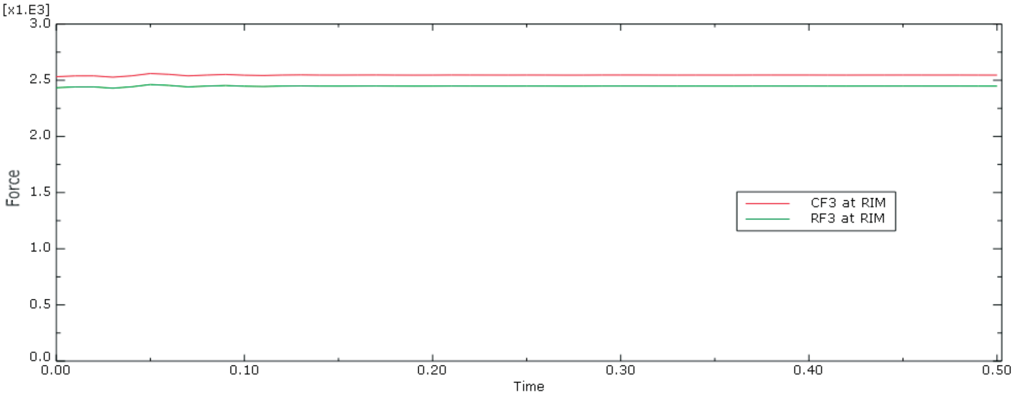

Figure 4–1 Magnitudes of CF3 and RF3 at the rim.

4.2 Example 2: Rigid vehicle model on a flat road

This example shows co-simulation between Abaqus and FTire for vehicle dynamic analysis. The model is a rigid full vehicle model. All the joint points are extracted from the Taurus model in the National Crash Analysis Center (NCAC). The original finite element model has been developed by The National Crash Analysis Center (NCAC) of The George Washington University under a contract with the FHWA and the NHTSA of the US DOT. All the suspension properties, such as spring, damper, bushing, and mass/inertia, might not be realistic since these properties are assumed.

The model is accelerated from 0 to 40 km/hr within one second. Then, between 1.5 and 2.0 seconds, a step-steer maneuver is performed by rotating the steering wheel.

In the Abaqus model, four point mass and rotary inertia elements are modeled as tires. For visualization, the rigid wheel shapes are also created in the Abaqus model. The nodes on the point mass and rotary inertia elements are attached to the FTire model. The rigid wheel is only modeled for visualization. In the FTire model, the default tire and flat road files in the FTire example directory are used.

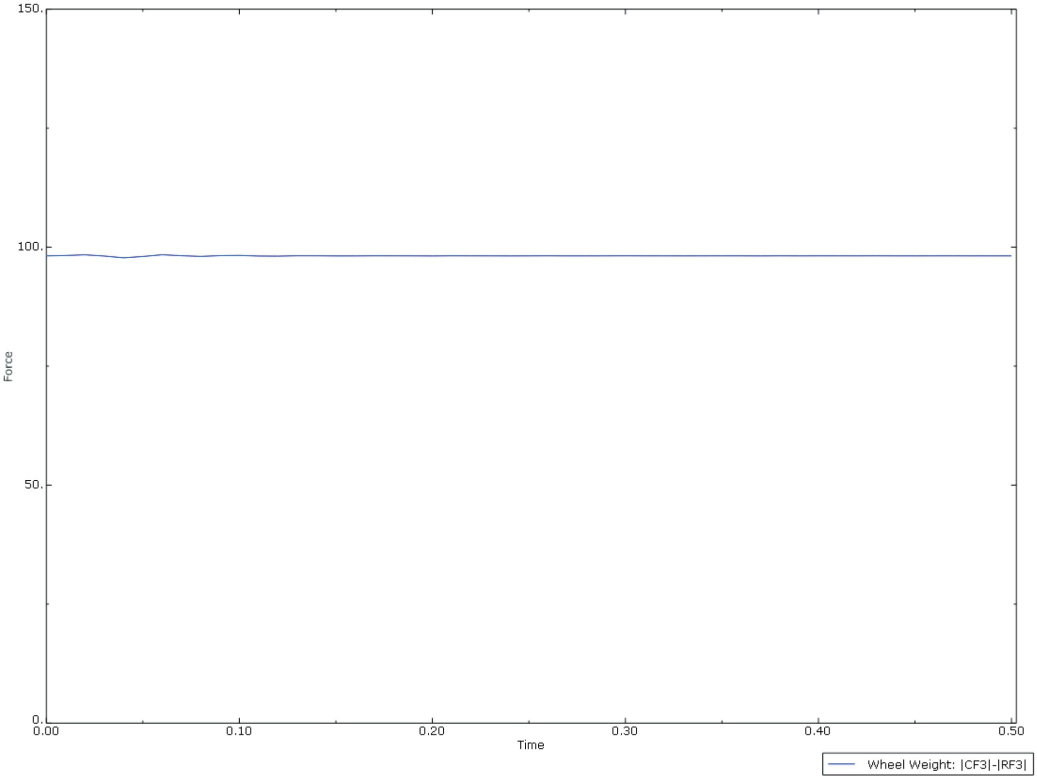

Figure 4–2 Magnitude of CF3 – RF3.

4.2.1 Example 2: Files

The following files are used in this example:

- **`Abaqus_full_vehicle.inp`**: Abaqus input file
- **`FTire_full_vehicle.inp`**: FTire input file for FTire co-simulation
- **`_default.tir`**: FTire tire property input file
- **`_default.rdf`**: FTire road input file

4.2.2 Example 2: Commands

The following commands are used to run the Abaqus and FTire co-simulation:

```
abaqus job=Abaqus_ full_vehicle csedirector=localhost:4000
   interactive
abaqus ftire input=FTire_ full_vehicle.inp port=4000
```

4.2.3 Example 2: Validation

The validation can be done by observing the vehicle maneuver, lateral acceleration, body roll angle, and the vertical tire force changes. Figure 4–3 and Figure 4–4 show the Abaqus model and the top view of the vehicle movement in the step-steer maneuver. As shown in Figure 4–4, the step-steer manuever is performed by turning the vehicle to the left. Figure 4–5, Figure 4–6, and Figure 4–7 show the vehicle body lateral acceleration, roll angle, and vertical tire force changes, respectively. The vehicle and tire systems are not in dynamic equilibrium at the start of the co-simulation, which introduces the initial oscillations. As shown in Figure 4–7, the right tire vertical forces increase more than the left tire vertical forces due to the weight transfer in the step-steer maneuver.

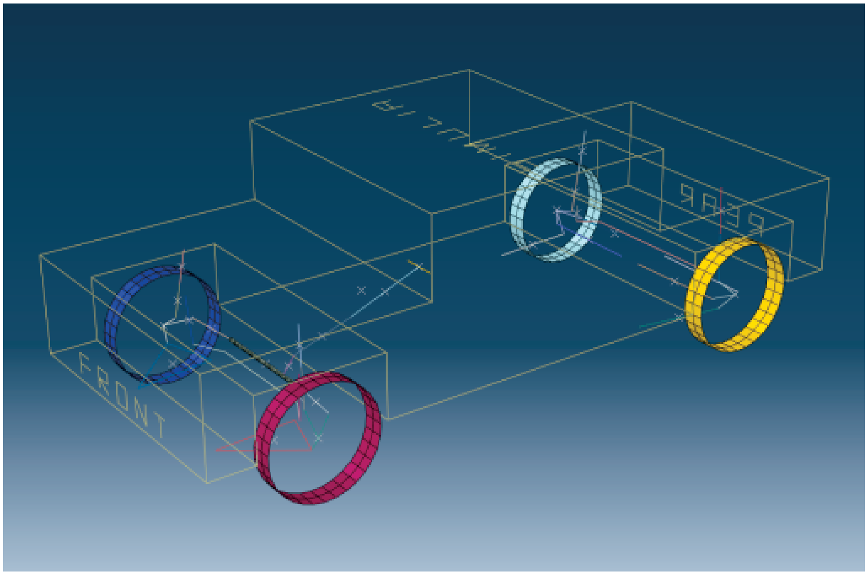

Figure 4–3 Abaqus model.

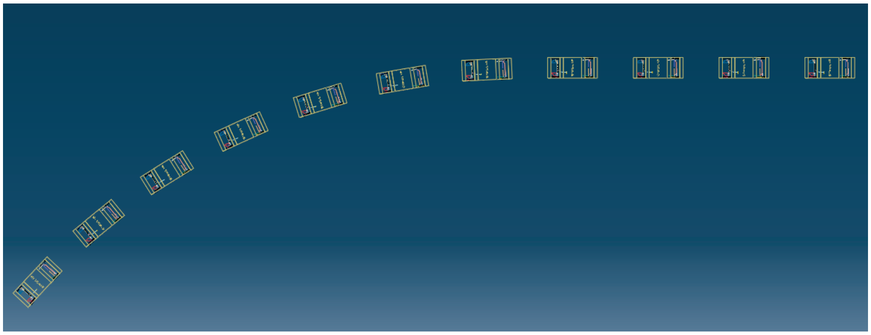

Figure 4–4 Step-steer maneuver of the Abaqus model.

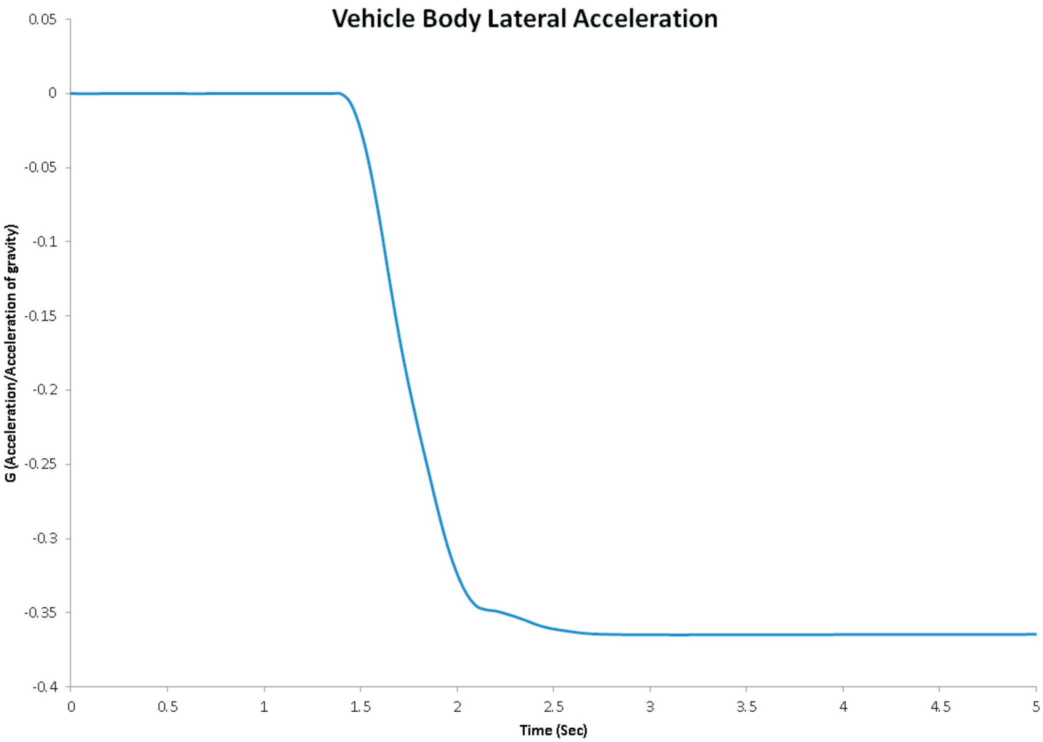

Figure 4–5 Vehicle body lateral acceleration.

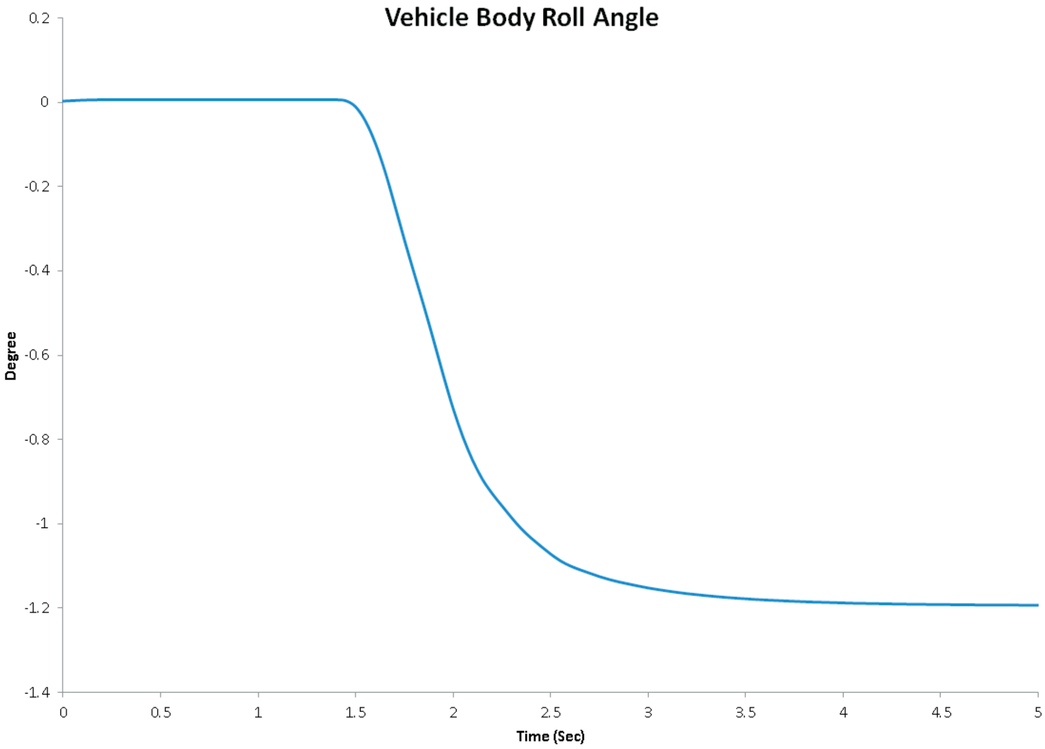

Figure 4–6 Vehicle body roll angle.

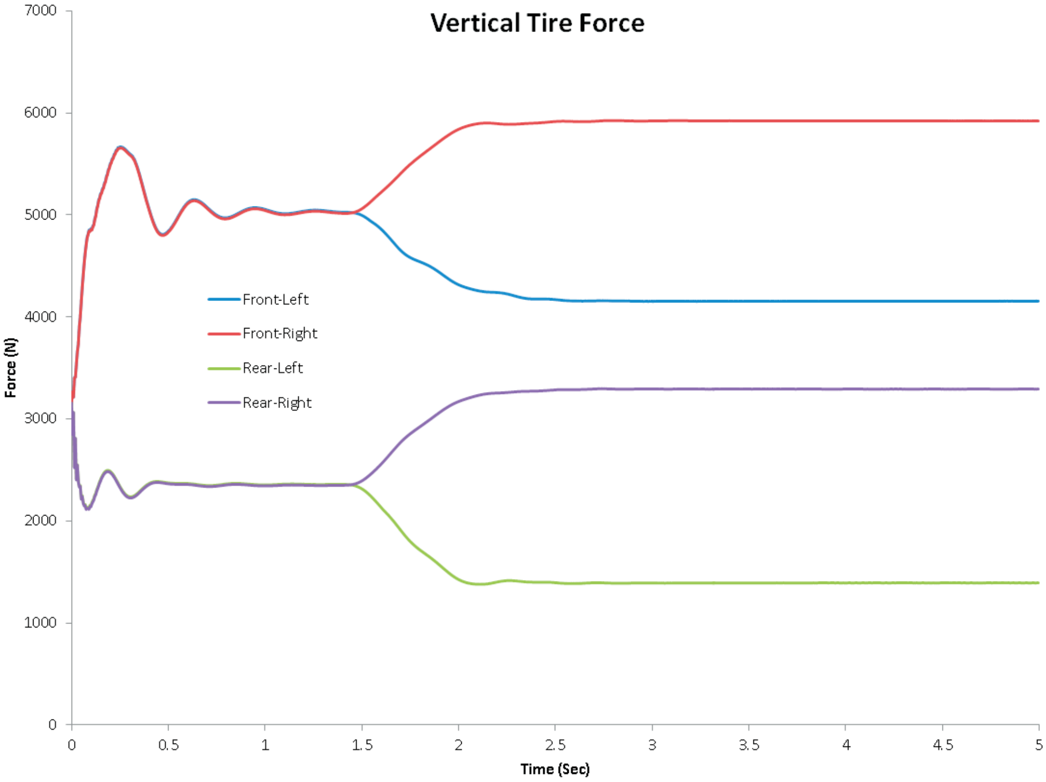

Figure 4–7 Vertical forces.

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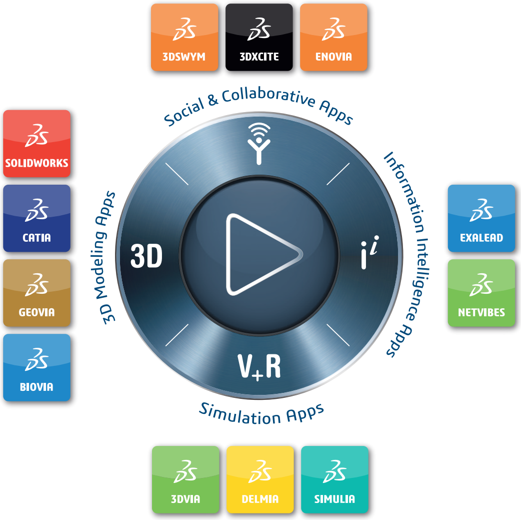

The **3D**EXPERIENCE® Company

Europe/Middle East/Africa
Dassault Systèmes
10, rue Marcel Dassault
CS 40501
78946 Vélizy-Villacoublay Cedex
France

Asia-Pacific
Dassault Systèmes K.K.
ThinkPark Tower
2-1-1 Osaki, Shinagawa-ku,
Tokyo 141-6020
Japan

Americas
Dassault Systèmes
175 Wyman Street
Waltham, Massachusetts
02451-1223
USA