

Multibody Dynamics Cosimulation for Vehicle NVH Response Predictions

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ABSTRACT

At various milestones during a vehicle's development program, different CAE models are created to assess NVH error states of concern. Moreover, these CAE models may be developed in different commercial CAE software packages, each one with its own unique advantages and strengths. Fortunately, due to the wide spread acceptance that the Functional Mock-up Interface (FMI) standard gained in the CAE community over the past few years, many commercial CAE software now support cosimulation in one form or the other. Cosimulation allows performing multi-domain/multi-resolution simulations of the vehicle, thereby combining the advantages of various modeling techniques and software.

In this paper, we explore cosimulation of full 3D vehicle model developed in MSC ADAMS with 1D driveline model developed in LMS AMESim. The target application of this work is investigation of vehicle NVH error states associated with both hybridized and non-hybridized powertrains. AMESim is responsible for generating the engine excitation, dampers, and detailed transmission, along with modeling the control strategy for powertrain component operations. Engine block, engine mounts, driveshaft, differential-axle unit, suspension, half-shafts, wheels, and body are modeled in ADAMS and imported as a functional mock-up unit in AMESim. Several key steady-state and transient error states are investigated. In particular, we look at the vibration response at the customer touch points due to transient phenomena generated by engine. Although a specific application of cosimulation is demonstrated in this paper, the methodology is general and can be used to simulate any powertrain system – vehicle combination. Hence data transfer between the co-simulating software is described and effects of key parameters, such as integrator type, time steps, and communication interval, on the quality of results are also investigated.

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INTRODUCTION

Use of simulation based engineering is becoming increasingly popular in automotive industry. Advances in computer technologies and simulation software make it ever more convenient to analyze mechanical dynamics of automotive system even before a physical prototype is built. This allows for an optimized design and helps catch, through computer simulation, potentially problematic design choices early on in a vehicle program's lifecycle. Applications of simulation engineering in automotive industry vary widely. A few examples are: combustion simulation for engine optimization, gear mesh force simulations, vehicle dynamics simulation and Noise, Vibration and Harshness (NVH) related simulations.

As mentioned above, different off-the-shelf simulation software packages specialize in different areas in terms of their applicability. Additionally, each simulation tool varies in its modeling philosophy. For example, in terms of required amount of input data, fidelity vs time to build a model, and so on. Given these differences in modeling and simulation software, sometimes the best way to simulate a phenomena under investigation is to employ two or more of such simulation software simultaneously; each tool working in its own area of specialization and coming together to simulate the whole phenomena of interest.

One such protocol that provides guidelines for communication between two simulation tools is the so called Functional Mockup Interface (FMI) standard [1]. This paper describes a cosimulation methodology developed using the FMI standard for Noise-Vibration-Harshness (NVH) simulations. The CAE software packages involved in this application are MSC ADAMS [2] and LMS Imagine.Lab AMESim [3]. Previously, Datar presented a cosimulation methodology using ADAMS and Powertrain Systems Analysis Toolkit (PSAT) for uncertainty analysis of vehicle-terrain interaction [4]. Felice et al. investigated the NVH and fuel economy trade-off using GT Power, ADAMS, and Romax cosimulation. The GT Power was used to model the powertrain component, detailed transmission internals were modeled in Romax, and ADAMS was used to model the 3D vehicle [5].

LMS Imagine.Lab AMESim is commercially available modeling and simulation software which is built upon the bond-graph modeling approach. Similar to Mathwork's Simulink, AMESim provides a multi-domain modeling flexibility to its users. Using a model-based engineering approach, mechatronic systems can be built quickly and analyzed in both transient and frequency domains. The models are categorized in different libraries which represent mechanical, electrical, hydraulic, powertrain, or thermal systems among many

other. Non-linear dynamic equations describing individual component behavior can be assembled together to represent entire system. The model-based engineering allows to simulate various characteristics of a system before 3D CAD geometry is available, thus AMESim can be used early in the product design cycle. Individual component such as sensors, gears, engine, links, and clutches are represented by icons with appropriate input and output ports. These icons can connected together to form a complete system with the notion of causality enforced by AMESim solver. Current version of AMESim allows both importing and exporting models in user friendly manner according to latest FMI standards.

ADAMS is commercially available multibody dynamics software which has found a wide range of engineering applications including those found in aerospace and automotive industry. Non-linear dynamics due to large translation and rotations, as well as due to contacts in multibody systems can be simulated effectively by Adams using relatively small amount of time as compared to a full finite element solution. In addition Adams also has limited capability to model multi-flexible-body systems using modal juxtaposition. Although not required, multibody model assemblies in Adams benefit greatly from available CAD geometry. This is especially true for problems involving contact. The equations of motion are constructed using Newton-Euler equations and the constraints are enforced using Lagrange multipliers. Adams also includes a number of different ODE solvers that can be incorporated according to user needs. Adams can be used as cosimulating software by exporting its model as FMU that can be imported in AMESim.

Following sections describe the motivation for developing cosimulation methodology and its applications.

MOTIVATION

The cosimulation environment described in this paper is developed in the context of powertrain (powerplant + drivetrain) induced NVH predictions. The goal of cosimulation is to leverage both AMESim and ADAMS by optimally using each of them for what they are good at to conveniently implement a simulation capability which would otherwise be cumbersome to achieve if one stuck to only one of the two software involved.

AMESim's library based approach offers a predefined set of components (for instance, V6/I4 engine excitation/engine block model) that can be readily modified and assembled to model an entire powerplant early on in the lifecycle of the vehicle program. These powerplant models include engine excitation, transmission, flywheels, dampers, torque converter, clutches, motor (for hybrid powerpacks), etc. These models are typically one dimensional (1D), meaning that they capture only torsional degree of freedom, but a generic three dimensional (3D) modeling (with all six degrees of freedom retained) can be utilized whenever appropriate. In the context of the work presented in this paper, the engine internals including the slider-crank mechanism and engine block are modeled as general three dimensional components while rest of the powerpack internals including the torque converter, torque converter damper, and transmission such as are modeled as 1D. This combined approach is able to capture 3D shaking forces/torques acting on the engine-

transmission (powerpack) block during a powerpack's steady state and transient operation. Further, AMESim model is also able to provide 1D torque coming out from the powerpack and acting on the driveshaft. Details on this modeling choice are explained later.

On the other hand, ADAMS is a fully 3D multibody dynamics modelling tool that is able to capture the physics of vehicle components that are tedious to model in AMESim. A typical vehicle model built in ADAMS includes driveline system with appropriate joints, differential unit with mounts, vehicle suspension, steering, sub-frame, chassis, anti-roll bar, tires and all the connections between these systems. Thus, with the use of an ADAMS vehicle model, one is able to predict the NVH attributes as experienced by the vehicle's occupants (customer touch-points responses like seat track and steering wheel vibration) in all directions. This is one of the main drivers for using a fully 3D vehicle model. In the context of this cosimulation framework, an engine-transmission block with appropriate bulk mass and mass moments of inertia properties is also included in the ADAMS vehicle model. This engine-transmission block receives three dimensional forces and torques coming from the 3D engine block in AMESim and responds to this input by vibrating on its mounts (also modeled in ADAMS). This engine-transmission block vibration then excites the rest of the vehicle through engine-transmission mounts. Thus, with this approach, one is able to study the effect of engine-transmission excitation as felt at the seat track and steering wheel during both steady state and transient events.

The next section describes the technical approach starting with two simplified models; a single degree of freedom spring-mass-damper translational system and a torsional degree of freedom system representing a simplified engine transmission system on mounts. These two simple systems serve as proof-of-concept models for the cosimulation framework. More elaborate results are presented by cosimulation of a 6 degree of freedom engine block model on mounts and seat track response of a full vehicle model to engine and halfshaft excitation.

TECHNICAL APPROACH

In order to implement the FMI cosimulation methodology for full vehicle NVH response analysis, it is essential to first check compatibility between the two CAE software packages and then test the various approaches using simpler, smaller models. In this section we describe the necessary steps that led to establishing the FMI cosimulation work flow and accuracy.

Single Degree of Freedom Mass-Spring-Damper

In a crawl-walk and run approach, it is beneficial to establish a very simple working system. This simple model could help understand the basics of a new methodology which is being investigated. Hence, although very simple, authors would like to describe a single degree of freedom system analyzed through a cosimulation approach.

Two equivalent models; a stand-alone model in AMESim and a cosimulation model using FMI protocol are shown in Figure 1. The stand-alone AMESim model is used to validate the cosimulation model. For cosimulation, the spring and damper are modeled in