International Journal of Modern Research in Engineering and Technology (IJMRET)
www.ijmret.org Volume 10 Issue 11 ǁ November 2025.

Integration of MBD Vehicle Models with Matlab/Simulink via FMI

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ABSTRACT : *This paper presents a Multi-Body Dynamics (MBD) model for the VW e-Up Boost electric vehicle using MSC Adams/Car software. The modeling utilizes Adams/Car's three-level approach with templates, subsystems, and full vehicle assembly. A key contribution is the integration with Matlab/Simulink through Functional Mock-up Interface (FMI) Co-Simulation, enabling co-simulation between different solvers and real-time data exchange. The paper addresses visualization challenges through Unreal Engine integration using Vehicle Dynamics Toolbox for realistic 3D simulation. This integrated environment enables comprehensive virtual testing of vehicle performance under various conditions without physical prototyping, reducing development time and costs while improving design optimization*

KEYWORDS – *VW Eup Boost, FMI, Adams/Car, Simulink, Co-simulation*

I. INTRODUCTION

Simulations play a key role in the modern vehicle development process. They enable virtual testing of functionality, reliability, and safety of components before their physical production. Thanks to simulations, development time can be significantly shortened, prototype costs reduced, and design optimization improved. An additional advantage is the ability to test extreme operating conditions and various configurations without the risk of damaging real components. Simulation tools thus enhance the quality and innovation of the final product.

II. VOLKSWAGEN E-UP

VW e-Up! (fig. 1) was one of the first affordably priced electric vehicles from Volkswagen, designed primarily for urban operation with compact dimensions and sufficient range for everyday use. [1] The front suspension utilizes an independent MacPherson strut suspension. The rear axle features a torsion beam axle. The front suspension is equipped with an anti-roll bar. Both front and rear suspensions are fitted with helical coil springs and shock absorbers. The electric motor is mounted at the front side of vehicle and drives the front axle.

Figure 1: Stock vehicle VW E-Up

The VW e-Up Boost (fig. 2) represents a modified sport model. The vehicle is equipped with an identical front suspension. Rear suspension, the torsion beam has been replaced with a MacPherson strut suspension, a rear anti-roll bar has been added, along with drive shafts powered by two Emrax 288 electric motors, located in the rear section of the vehicle.

Figure 2: Sport version VW E-Up Boost

III. MBD MODEL OF VW E-UP BOOST IN ADAMS/CAR

The Adams/Car program uses a three-level vehicle modeling system [2],[3]:

1. Template. Templates are parametric models that define topology of models. Basic property of every template is Major Role, which defines the functional part of the vehicle e.g. suspension, steering, …. Every template contains special model elements called communicators, which main role is exchanging data later in assembly.
2. Subsystem. Subsystems are based on templates and allow users to change the parametric data of the template as well as the definition of some components. Basic property of every subsystem is Minor Role, which defines the functional area of the vehicle template.
3. An assembly represents a collection of subsystems, along with optional test rig, which when assembled forms a system that can be analyzed and simulated using Adams/Solver.

Fig. 3 shows schematic of VW E-Up boost MBD model in Adams/Car. Used templates (red blocks), their major roles, subsystems (blue blocks), their minor roles, assembly (green block). Used model presented in paper is full vehicle assembly (fig. 4).

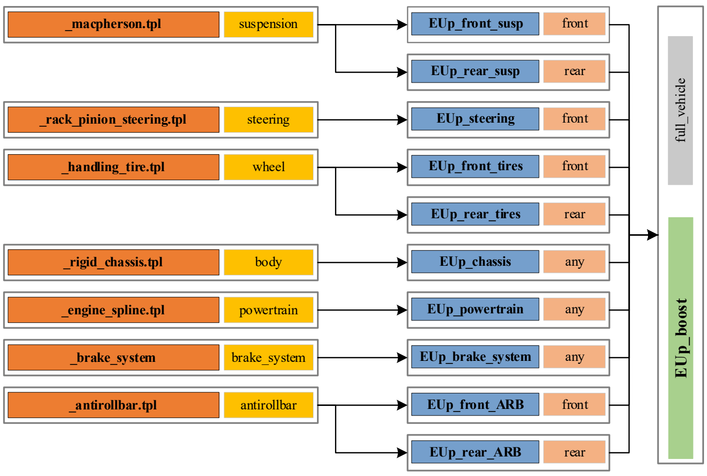

Figure 3: Block diagram of VW E-up Boost vehicle in Adams/Car

Figure 4: MBD model of VW E-up Boost vehicle

IV.Simulation of Full Vehicle Assembly

The Driving Machine in Adams Car is a software module (a virtual driver) that controls the entire vehicle during simulation. The Driving Machine (fig. 5) steers the vehicle, applies the throttle and brake, and shifts gears (using the clutch). The Driving Machine can operate in open-loop mode (without feedback) or in closed-loop mode (with feedback). Adams SmartDriver is an advanced driver simulator that can bring a vehicle to its dynamic limits (Closed Loop). Adams SmartDriver is not used in this article. [2],[3]

An event in Adams Car is a test maneuver that defines what happens to the vehicle during the simulation. An event is represented by an xml file that contains data for defining and transmitting sets of command signals, feedback signals, and parameters for each of the five control inputs: steering, throttle, brake, gear, and clutch.

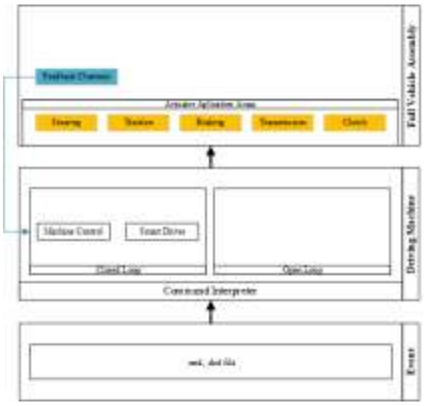

Figure 5: General scheme of driving machine

Event is defined for five control signals (steering, throttle, brake, gear, and clutch) separately; therefore, Driving Machine can be defined as Pure Open Loop, Pure Closed Loop or Combination of Open and Closed Loop. [5],[6]

V.Functional Mock-up Interface

The Functional Mock-up Interface is a free standard that defines a container and an interface to exchange dynamic simulation models using a combination of XML files, binaries and C code, distributed as a ZIP file. It is supported by 250+ tools and maintained as a Modelica Association Project. [4]

A Functional Mock-up Unit (FMU) is the executable that implements the interface defined by the Functional Mock-up Interface (FMI) standard.

FMI standard supports two types of co-simulations:

- Model Exchange:
  - The FMU (Functional Mock-up Unit) provides only the model equations (e.g. ODEs, DAEs).
  - The solver is external — it's provided by the master simulator (e.g. Simulink, Dymola, etc.).
  - The master controls Time integration, Step size, State events.
- Co-Simulation:
  - The FMU includes its own solver.
  - Each FMU advances independently in time over given steps.
  - The master only coordinates time steps and data exchange.

MSC Adams can export and use FMU only in Co-Simulation mode, not in Model Exchange and supports FMU v1 and FMU v2. Each exported FMU from Adams contains [5]:

- Complete Adams model (.adm, .acf files).
- Driving event (.xml files).
- Necessary dlls files.
- Necessary property model files (e.g. tire models).

Fig. 6 shows used connections presented in paper utilizing FMI where Matlab/Simulink is Master and Adams (represented by FMU) is slave.

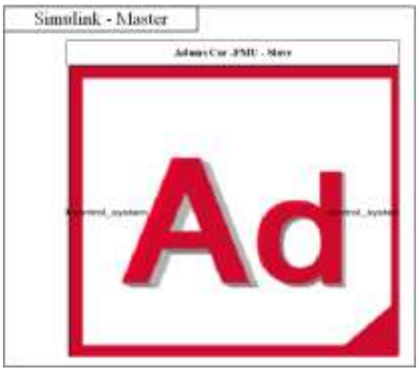

Figure 6: Used FMI interconnection

A. Control system template

For communication and data exchange between the Master solver (Simulink) and the vehicle FMU, it is necessary to create and integrate a control system into the vehicle MBD model. The control system will communicate using state variables during co-simulation.

Presented Control system is based on 12 markers (fig. 7):

- Black marker is connected to ground.
- Orange markers are connected to vehicle chassis.
- Green markers are connected to wheel spindles.
- Blue markers are connected to uprights.

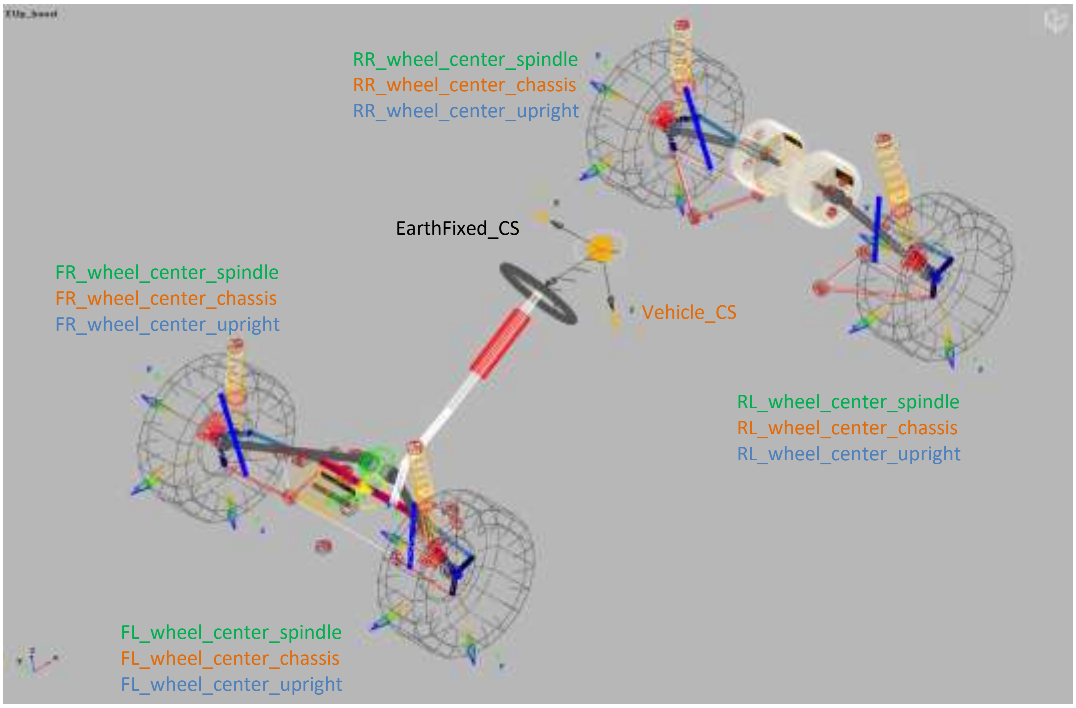

Figure 7: Markers used in Control system

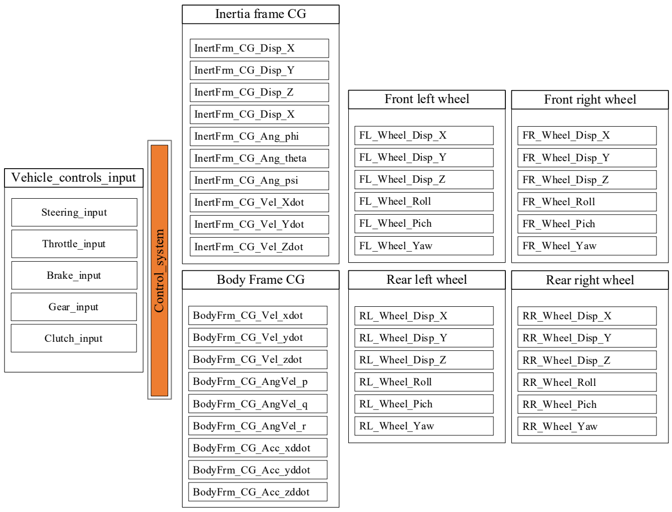

Figure 8: Computed state variables in Control system

All state variables are computed using Adams run-time functions with necessary markers (fig. 7) [5]:

- Displacements: DX, DY, DZ.
- Rotational displacements: AX, AY, AZ.
- Velocities: VX, VY, VZ.
- Angular velocities: WX, WY, WZ.
- Accelerations: ACCX, ACCY, ACCZ.

B. Visualization of vehicle

One of the problems which can arise during the co-simulations of FMU vehicles is visualization of vehicle position and orientation during the simulation. The solution may be to use Unreal Engine in combination with Vehicle Dynamics Toolbox. Fig. 9 shows vehicle model in Blender, which can be imported to Simulation 3D Vehicle block as FBX file. Simulink model used for test is shown in fig. 10. [7]

Figure 9: VW Eup Boost in Blender

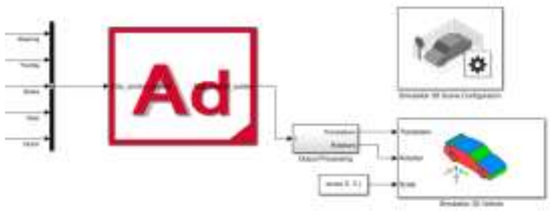

Figure 10: Example Simulink model

Figure 11: Visualization in Unreal Engine

VI. CONCLUSION

This paper has demonstrated the successful development and integration of a comprehensive simulation framework for the VW e-Up Boost electric vehicle, combining MSC Adams/Car MBD modeling with Matlab/Simulink through the FMI standard. The primary advantage of this approach lies in its flexibility and modularity, enabling seamless integration of detailed vehicle dynamics models with advanced control algorithms and real-time visualization capabilities. The three-level modeling structure in Adams/Car provides a systematic and reusable framework for vehicle development, while the FMI Co-Simulation interface allows independent solver operation and efficient data exchange between different simulation environments.The integration with Unreal Engine addresses a critical challenge in virtual testing by providing realistic 3D visualization, which is essential for validation and presentation purposes.

However, several limitations should be acknowledged. The Co-Simulation approach, while flexible, may introduce synchronization challenges and potential accuracy issues at integration points, particularly when dealing with stiff systems or discontinuous events.

The practical applications of this framework extend beyond the specific case study presented. The methodology can be readily applied to various vehicle configurations.

The framework could be enhanced by implementing Model Predictive Control (MPC) algorithms for advanced vehicle motion control or by incorporating machine learning models for predictive maintenance and adaptive control strategies. Furthermore, expanding the visualization capabilities to include augmented reality (AR) or virtual reality (VR) interfaces could provide immersive experiences for design review and training purposes.

Acknowledgements

This research was supported by the Slovak Research and Development Agency under Contracts No. SK-SRB-23-0024.

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