Adams-EDEM Co-simulation for **Predicting Military Vehicle Mobility on Soft Soil**

By **Brian Edwards, Vehicle Dynamics Group, Pratt and Miller Engineering, USA**

Multibody Dynamics (MBD) models of wheeled and tracked vehicles can be validated and used to predict behavior on hard surfaces for a wide variety of events. However, when the vehicle is simulated over a deformable terrain, no current methodology can fully represent the dynamic interactions of the vehicle and the soft soil. When designing a vehicle, engineers will often resort to using their past experience with physical testing to predict how the vehicle will behave once it leaves the hard road surface. Only when the vehicle is built and tested, can they obtain the actual data for how the vehicle performs over soft soils. And for many low-rate or expensive vehicles, the prototype may actually be the end product as well, requiring major modifications to the physical vehicle once off-road testing is performed. Accurately modeling the terramechanics is key to understanding the mobility characteristics of off-road vehicles, and understanding how changes to the vehicle and terrain will impact the dynamic behavior.

Discrete Element Models (DEM) represent the soil as individual particles, with complete free body motion between other particles as well as any physical objects they encounter. DEM is a particle-scale numerical method for modeling the bulk behavior of granular materials and many geomaterials, including coal, ores, soil, rocks, aggregates, pellets, tablets and powders. EDEM® from DEM Solutions is one of the leading solutions in this space.

DEM allows for particles to break down or separate from the material bed, and can easily represent particles of varying size and shape. Different particle types may be mixed together to obtain a non-homogenous material, or layered on top of each other as needed. Since the particles dynamically act in 3-D, lateral bulldozing effects, soil accumulation on wheels or tracks, as well as vertical surface features like hills can be easily represented by the soil model. Additionally, the particles may be compacted once or multiple times to provide a variety of soil conditions.

Integration of MBD and DEM Models

In order to simultaneously solve an existing MBD vehicle model with a separate DEM soil model, co-simulation is required to allow each solver to accurately calculate the dynamic behavior of the vehicle-soil interactions (Figure 1). The forces and displacements of the MBD/DEM objects must be shared between each program, via a structured interface that connects and manages the communication.

When integrating an MBD model with a soft-soil EDEM model, the traditional vehicle-road forces are replaced with corresponding forces between the vehicle and the soil particles. The MBD model supplies geometry locations at each integration step, and the EDEM model then calculates the particle forces acting on the equipment parts based on the

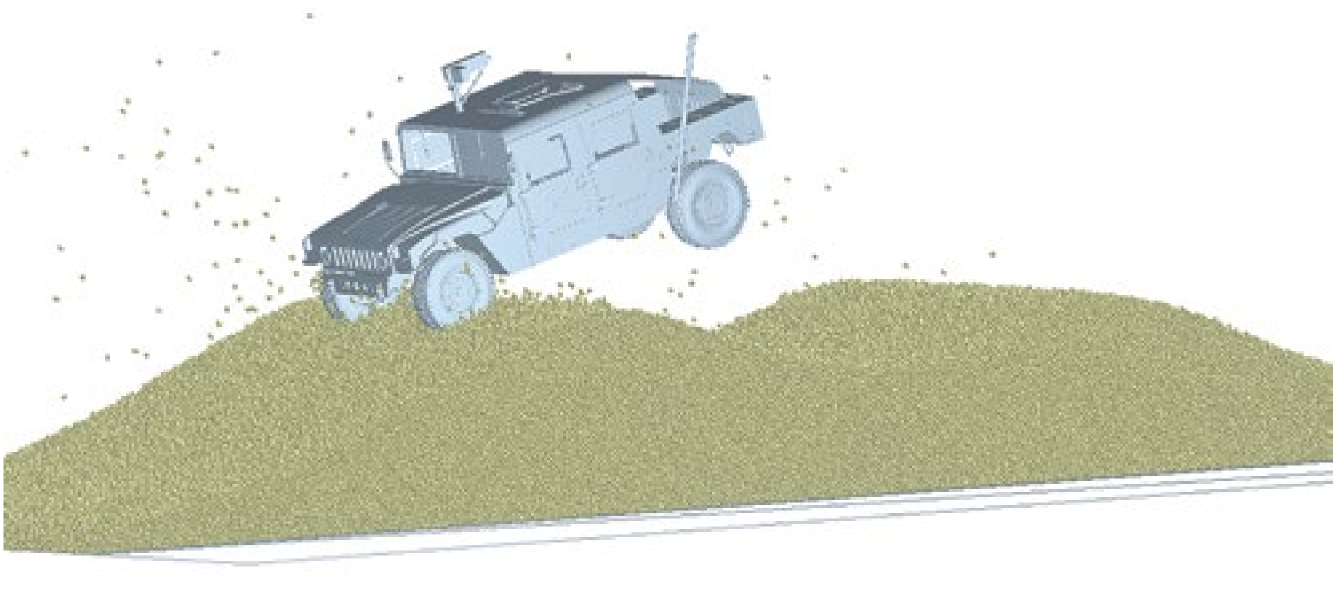

Figure 1. Adams-EDEM Co-simulation

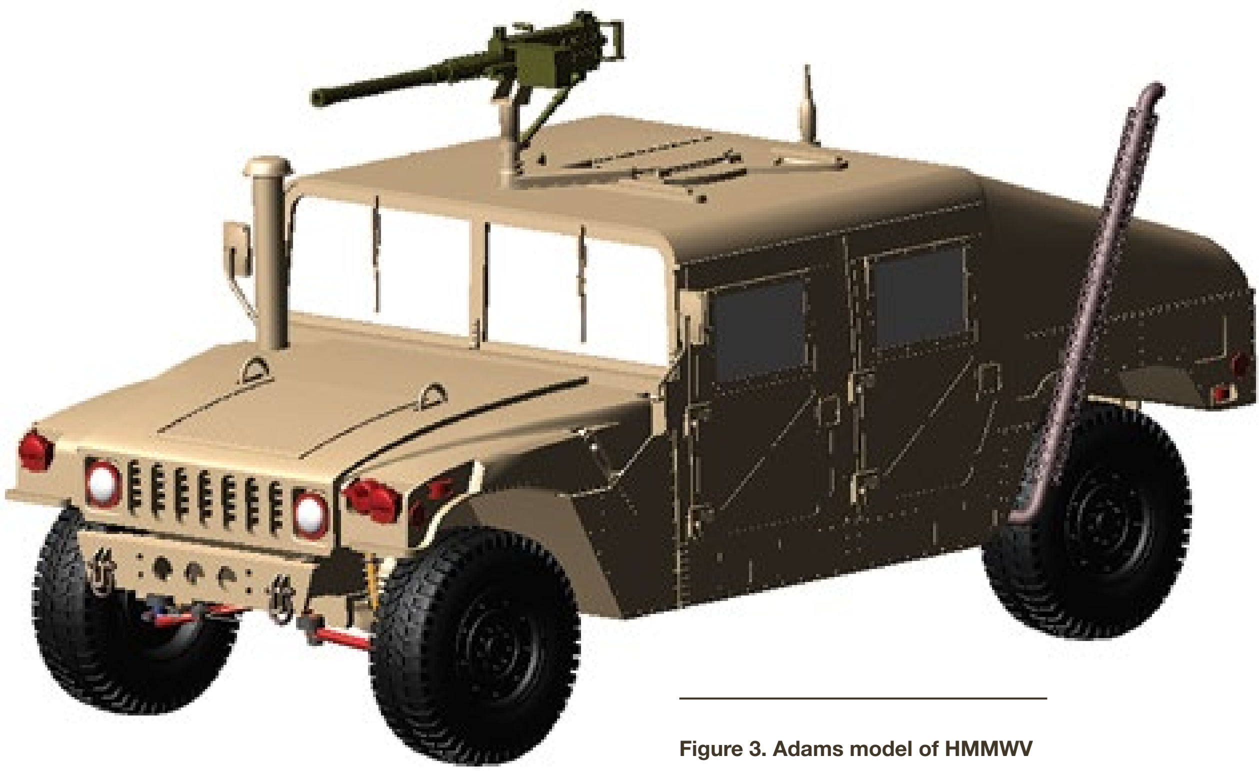

Figure 3. Adams model of HMMWV

discrete particle model employed. The resultant force on each geometry is then communicated back to the MBD model, which uses the forces during the subsequent dynamic time step.

Model Preparation for Co-Simulation

The first step towards integrating an MBD model with a DEM soil model is to validate each model within its own domain. By isolating this initial verification phase, each model can be tested independently to ensure the behavior meets the desired specifications.

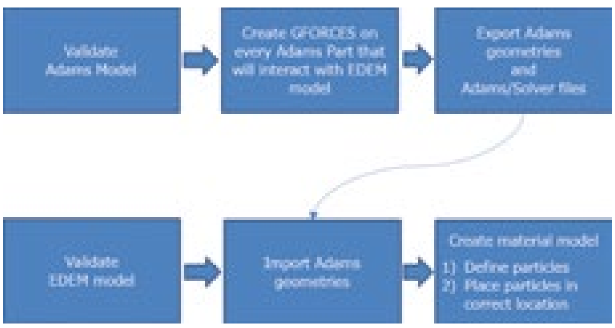

Figure 2. Adams - EDEM setup workflow

After the MSC Adams MBD model is validated, the next step is to determine which geometries will potentially come into contact with the soft soil. For a wheeled vehicle, this might be as simple as the four tires. In contrast, a tracked vehicle will require many more contact geometries, including the track segments, connectors, wheels, and hull. For each of the Adams parts containing the corresponding geometry, a GFORCE element is created which will hold the force value calculated by the EDEM soil model.

The EDEM soft-soil particles must be configured to represent the desired MBD-EDEM testing scenario. For instance, if a flat terrain is desired, then the appropriate dimension of the particle bed needs to be determined. The width should be enough to ensure that any lateral particle displacement does not build up against the side boundaries, and the length should be long enough to perform the vehicle maneuver.

Once the EDEM particles are prepared, the vehicle geometries exported from the Adams model are then imported into EDEM. The geometries are imported such that a single EDEM geometry is created for each corresponding Adams part.

With the Adams and EDEM models ready for simulation, the final step is to define a communication protocol for the integration of the models. The Adams Co-Simulation Interface (ACSI) is a framework that provides the topological interface between Adams and other software via a configuration script and corresponding glue code. The ACSI controls the co-simulation, allowing for asynchronous communication and various interpolation and extrapolation algorithms.

When the ACSI interface is started, the configuration file supplied will define how the Adams and EDEM models share data at each communication step. The Adams model will provide the location of each GFORCE, and the EDEM model will then assign that location to the corresponding EDEM geometry. Based on this geometry displacement, the EDEM solver will calculate the bulk behavior of the soil particles, and determine the composite particle force and moment on each EDEM geometry object. This force is then communicated back through the ACSI which assigns the values to the corresponding GFORCE elements. These forces are then included in the next dynamic time step the Adams solver takes.

Model Definitions

Two separate Adams vehicle models were defined for the original paper: a wheeled vehicle, and a tracked vehicle. In this article we are going to talk about the wheeled vehicle only. An EDEM ground material model was developed and used for all the different co-simulations.

A. Adams Wheeled Vehicle Model

An Adams model of a HMMWV (Humvee, see Figure 3) was used for development and validation. This HMMWV Adams model had been previously used for hard surface simulations, and the behavior verified using various test maneuvers. The initial integration with the EDEM particle model included only the four tires as contact objects with the terrain; subsequently, the body and certain exposed suspension elements were also exported for use during co-simulation.

B. EDEM Ground Material Model

Extensive testing and correlation has been performed by EDEM users to define particles that match the behavior of the desired physical soil. To aid users in obtaining particle models that behave as desired, EDEM provides the GEMM Material Database, where users can lookup pre-defined materials based on three inputs: the scale of the application; the angle of repose; and the bulk density of the material. Finally, the EDEM Soil Starter Pack provides eight sample out-of-the-box materials with different ranges of compressibility and stickiness.

Figure 4 shows a double hill terrain configuration used for both the HMMWV and Tank Adams models. To create this test case, the Adams road surface was imported into EDEM, and then a fixed quantity of particles was dropped onto the road, with the particles forming a natural rounded hill based on the material properties. The same amount of particles was then dropped onto the road at a fixed offset location,

Figure 4. Double hill terrain in EDEM

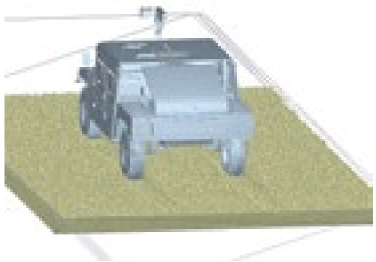

Figure 5. HMMWV on flat terrain at 20kph

Figure 6. HMMWV on single hill at 20kph

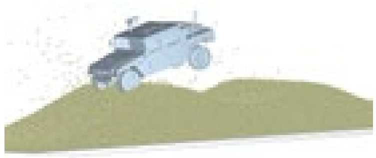

Figure 7. HMMWV on double hill at 60kph

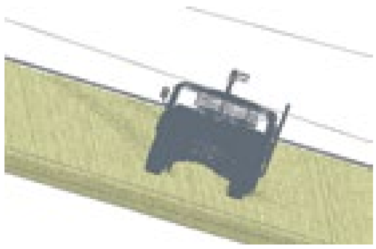

Figure 8. HMMWV on 30 percent side slope at 25kph

creating the second rounded hill in the background, which has a slightly higher peak than the first hill.

Simulation Results

The Adams HMMWV model was simulated over a variety of soft-soil terrains, using the same EDEM particle model in each case. The first maneuver is the HMMWV traversing a flat particle bed as shown in Figure 5.

The HMMWV was then run over a single hill at various speeds to investigate the ability to traverse the obstacle, as well as the power required during the event. Figure 6 shows the HMMWV at 20kph trying to climb the hill, and getting the front wheels stuck in the soft soil.

At a high speed, the HMMWV becomes airborne as it crests the hill. Based off this behavior, the HMMWV was run over the double hill at various speeds, with the vehicle impacting the ground at different points based on the velocity. When running at 60kph as shown in Figure 7, the HMMWV lands just before the crest of the second hill, with the impact "splashing" the soil particles.

In order to run the HMMWV on a side-slope, the vehicle starts out on a level hard road surface, which then gradually rotates until it reaches the desired slope gradient. At this point the hard surface ends and the soft soil begins. The steering controller in the Adams model is set to try and maintain a straight-line while on the side-slope. Figure 8 demonstrates the vehicle behavior as it leaves the hard surface and enters the material bed. The vehicle initially slides down the slope as the steering reacts to the lessened traction available, and compensates until the vehicle begins to recover towards the desired straight-line path.

Co-Simulation Results

A. HMMWV Results

Two of the simulation results for the HMMWV model are discussed below. First, for the vehicle traveling across the flat terrain; second, when the HMMWV is traversing the 30% side slope.

One important validation step was to compare the tire forces when the vehicle is on the hard surface, against the forces when it is crossing the soft soil. Figure 9 shows the forces between the left rear tire and ground during the entirety of the simulation. Up until around time=1sec, the HMMWV is on the hard surface, and the tire forces are calculated through the standard Adams Tire routines (shown in red). As the vehicle transitions onto the soft soil, the Adams

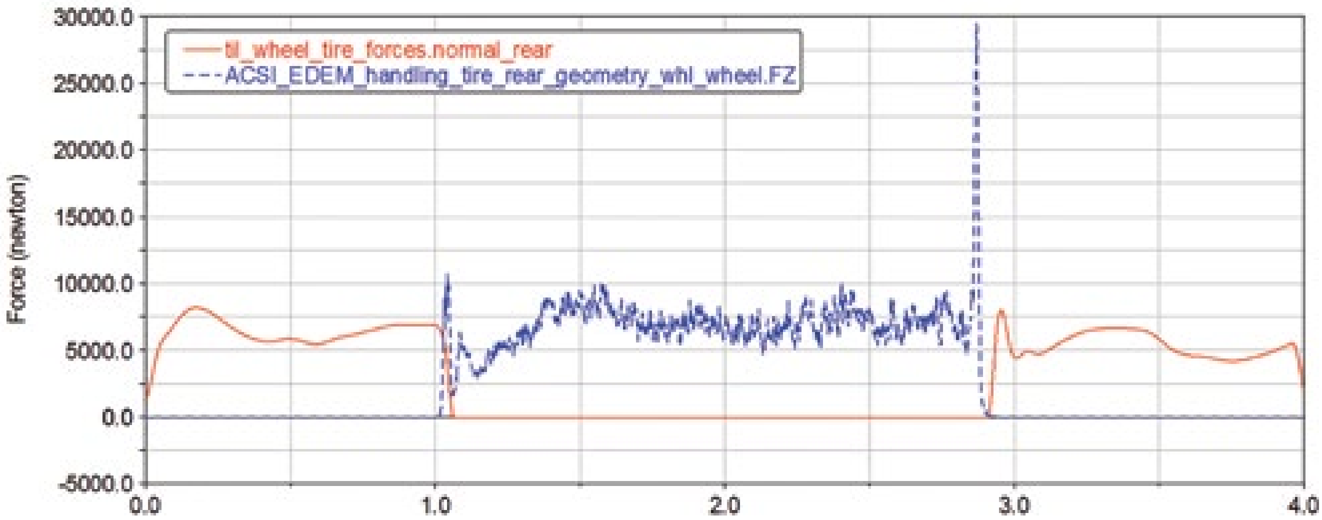

Figure 9. HMMWV tire and particle forces

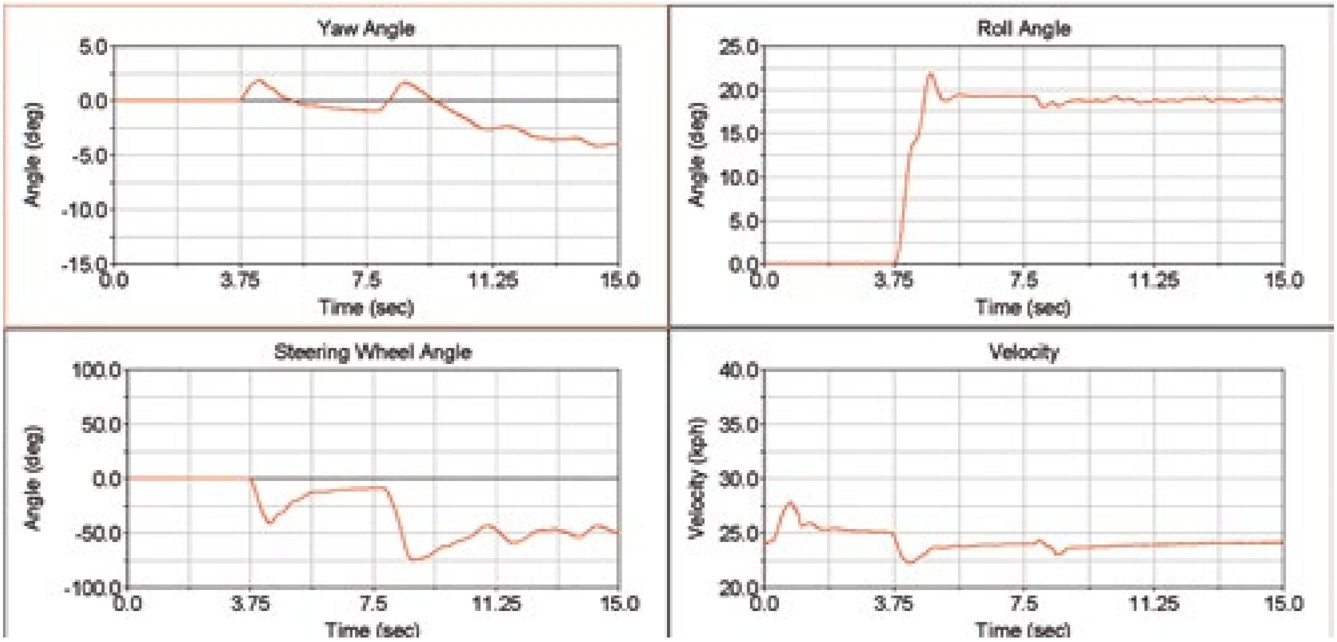

Figure 10. HMMWV on 30% side slope

Tire forces go to zero, and the EDEM particle forces (shown in blue) begin to carry the load. After an initial transient phase, the vehicle stabilizes and the contact forces calculated by the EDEM particles are equivalent to the tire forces on the hard surface.

As the HMMWV exits the material bed, there is a spike in the EDEM particle force, due to a localized particle effect at the transition from soft soil to hard surface (a scaled soil particle which was pushed onto the hard surface is traversed). Once the vehicle returns to the hard surface, the tire forces again are calculated by the Adams Tire method.

The HMMWV side slope maneuver (slope downward from right-to-left) provided an opportunity to investigate the behavior of the vehicle as it transitioned onto the soft soil, and the vehicle's ability to maintain a straight-line course once on the EDEM particles.

The simulation begins with the HMMWV on a flat, hard road surface, at a constant speed of 25kph. At time 3.75 seconds, the hard surface begins to gradually roll, until at about a time of 5.5 seconds the 30% side slope is achieved. The vehicle continues on the hard side slope road until around time 7.6 seconds, at which point the hard surface ends and the soft soil begins. The EDEM particle bed was positioned to match the slope of the hard surface to the soft soil; however, as seen in Figure 10 there is a transient response as the vehicle enters the deformable terrain.

As the front wheels of the HMMWV enter the particle bed, the vehicle initially yaws to the left while the rear

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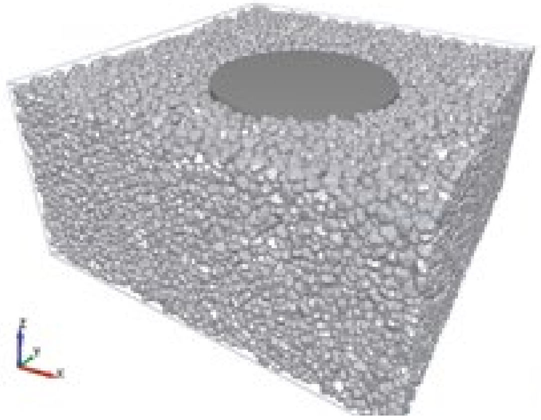

Figure 11. Adams-EDEM test rig for soil parameter characterization

wheels are still on the hard surface. Once the entire vehicle is on the soft soil, it begins to drift down the slope, and the steering controller increases the angle to return to a straight line course, causing the vehicle to yaw in the opposite direction. At the end of the simulation, the yaw has stabilized and the steering angle is maintained at about 50 degrees to travel in a straight direction.

B. Correlation of Adams-EDEM Soil Properties with Bekker-Wong Parameters

The process of co-simulating the Adams MBD vehicle model alongside the EDEM DEM soil model, introduces a new dimension to the established procedure for verifying DEM soil properties. When the entire solution is performed inside a DEM environment, the force/displacement interactions are all internally computed. With the Adams-EDEM co-simulation, each software solves its own equations, communicating the displacements and forces at the established communication intervals. Additionally, the dynamics of the vehicle can generate rapidly changing displacements and force values between the vehicle and soil particles.

A testing procedure has been proposed (reference 1) for validating the Adams-EDEM implementation. The test rig will be created inside an Adams MBD model, with the pressure/force also being defined in Adams. The test rig geometry will be exported from Adams and imported into EDEM, and then filled with the desired soil particles (see Figure 11). The Adams-EDEM co-simulation will then run, applying the specified force or pressure to the plate, with the Adams simulation results post-processed to generate the corresponding Bekker-Wong parameters.

Reference

1. "Co-Simulation of MBD models with DEM code to predict mobility on soft soil", Brian Edwards, NDIA Ground Vehicles Systems Engineering and Technology Symposium, 2018, Michigan USA.