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ADVANCED SIMULATIONS FOR MOBILITY PREDICTIONS IN VARIABLE TERRAIN PROFILES

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ABSTRACT

The NATO Reference Mobility Model (NRMM) is an empirically based tool developed to facilitate comparisons between vehicle design candidates and to assess their mobility under specific mission profiles. It was originally established in the 1960s and 1970s, during a time when modern computational methods were in their infancy. Since its initial development, the NRMM has been revised and updated several times, but there has always been a deficiency – a thorough understanding of the vehicle capabilities for each mission profile.

With the advent of modern simulation tools, coupled with the latest in data visualization and analytics, a new generation of mobility models may be built that cannot only assess a vehicle's mobility, but also understand its extended range in various soil types, and more specific terrains or operational conditions.

This presentation will discuss the capabilities of advanced simulation and visualization software and their ability to affect how mission planning and profiling could be conducted to ensure mission success and improve warfighter safety.

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1. Introduction

Prediction of vehicle mobility impacts many aspects of the development, deployment and use of a vehicle. As vehicles performance specifications are developed and translated into a design and eventually into physical prototype that can be field tested, the ability to predict the effectiveness of that vehicle to traverse various terrains and soil types is critical.

Historically, that prediction has been performed using vehicle design data, entered into an empirically derived calculation tool, called the NATO Reference Mobility Model (NRMM). While this has provided a fundamental prediction of the ability of vehicles to maneuver in various terrains and soil types, the capability to evaluate novel vehicle designs quickly and effectively to study design tradeoffs, has been limited, due to its reliance on an underlying database of vehicle architectures and terrain data. In many vehicle deployment cases, the terrain, moisture content and soil types could vary greatly in a local region, making the NRMM prediction an unreliable predictor of vehicle mobility.

Since the development of the NRMM, many new computational approaches have been developed and widely used in automotive and commercial vehicle industries that could be applied to the development and evaluation of defense vehicle mobility. One such computational method is referred to as Multi-Body Dynamics (MBD). This paper will discuss the approach of using MBD as a method to evaluate mobility under a variety of terrain conditions. We will continue, discussing the opportunities that this type of simulation provides to enhance the predictive ability of vehicle developers, and those deploying vehicles for specific mission profiles.

The development of the Next Generation NRMM (NG-NRMM)[1] provided an opportunity to evaluate MBD modeling technology, as applied to different levels of terramechanics modeling. This paper will review results obtained using simple and complex terramechanics models for test conditions such as Sand Pit Maneuver and a Drawbar Pull. These simulation results will be compared to vehicle tests that were done on a tactical wheeled vehicle at Keweenaw Research Center in Calumet, Michigan as part of a NATO Cooperative Demonstration of Technology (CDT), September, 2018 [2].

Additionally, as the vehicle performance is predicted using these simulations, the development of go/no-go maps can offer information to those involved in mission planning and real time operations. That information can be aggregated into a map along with other GIS data to facilitate route planning.

2. Multi-Body Dynamics Software

Multi-Body Dynamics software is used by many industries in the design, development and evaluation of mechanical systems. From the initial development in the 1970s, through today, these methods allow the engineer to study the physics of systems in motion. MSC Software develops and distributes MBD software, MSC Adams™, which is widely used in the development of complex mechanical systems.

Application to vehicle systems was a natural application, as the complexity of vehicle suspension systems and the interaction with tires and roads, make them difficult to analyze using classical methods, especially when the road surfaces and suspension behaviors may vary greatly in use.

3. Terramechanics: Soft Soil Modeling

Since MBD software such as MSC ADAMS™ can simulate the contact between model elements, this ability can be applied to the tire/road, tire/soil, track/soil interaction. This provides a way to account for the penetration of the tire/track into the soil and the resulting tractive forces created in that situation. Models can comprehend the changing behavior as is moves between wet/dry soil conditions, or as a vehicle may only partially interact with a varied soil condition (so called “split-mu” conditions).

3.1. Simple Terramechanics

Road surface models used in MSC Adams™ simulations may be rigid or deformable. The deformable road surfaces may be used to simulate a vehicle behavior, stability, power consumption, tractive effort, etc. under various road conditions. The definition of deformable roads can take the form of a normal road surface, with additional data supplied to define the soft soil parameters.

The soft soil modeling interaction is based on the work by Bekker, Wong, Janosi, Ishigami and Schmid. For purposes of this paper, this approach to defining the deformation via soil testing parameters is referred to as a 'simple terramechanics' method.

3.2. Complex Terramechanics

Recent developments in MSC Adams™ allow for co-simulation with Discrete Element Modeling (DEM) approaches. Studies have been performed that demonstrate the capability of this approach to deliver a soft soil modeling as applied to off road tactical vehicles[4]. For purposes of this paper, we are referring to this approach as a 'complex terramechanics' method.

As geographical information is now widely available, such as satellite or vehicle mounted LIDAR scans, the use of that information to construct road surface models can provide a means to describe varied terrains, such as those encountered in off-road scenarios.

4. Traction Behavior Prediction using Simple and Complex Terramechanics

MSC Adams™ supports simple terramechanics through an implementation of the Bekker-Wong formulas for calculating tire forces based on soil deformation and wheel kinematics (slip, etc.) In contrast with the analytical formulations of bulk properties used by simplified terramechanics, it is possible to implement methods where these bulk properties emerge from particle interactions. For these cases, in which the granular behavior of soil is to be accurately modelled, the approach is referred to as discrete element method (DEM).

4.1. Drawbar Pull Test

Drawbar Pull tests are performed in order to characterize the available tractive force of a given vehicle on a specific soil. They are considered a key indicator of vehicle capability on deformable terrain. The tractive effort curve of the test vehicle was generated on fine-grained soil surface using a time-domain vehicle simulation where the vehicle attempted to maintain a steady speed while subjected to an increasing drag load. Initially, before any terrain simulations, the drawbar pull test results were generated on fine-grain wet soil as a part of the validation effort with test. The traction behavior predicted from the simulation model employing both Bekker-Wong and DEM calculation methods is compared in the figure below. It is found that the DEM approach is closely predicting the traction behavior of the soil better at lower critical slip limits(<30%). The Bekker-wong approach over predicts the traction limits of the soil and is highly dependent on the accuracy of the sinkage parameters calculated from the soil tests.

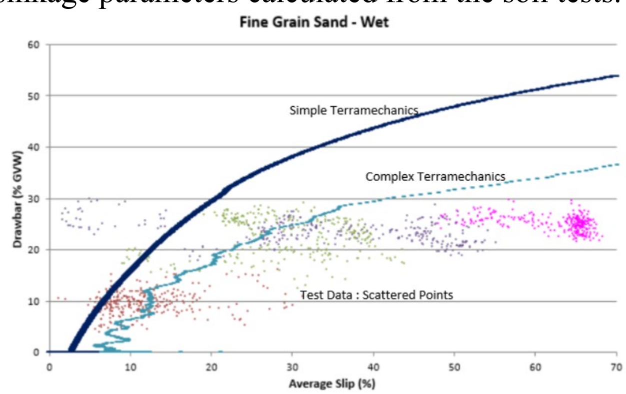

Figure 1: Traction Behavior: Test vs Simple & Complex Terramechanics predictions

5. Vehicle Mobility Predictions

The objective of the mobility analyses were to assess vehicle performance for a terrestrial scanned traverse over composite virtual terrain (hard and soft soil combination). The terrain was modeled from LIDAR scanning data, and soil types were identified from physical tests using a bevometer and cone penetrometer. Descriptions of these devices can be found in Reference 2. For these simulations, the target vehicle path was provided and implemented within MSC Adams™ for use by the vehicle steering controller. The figures below show some of the evaluated terrain segments for maximum obtainable end-to-end speed that were compared to the test predictions.

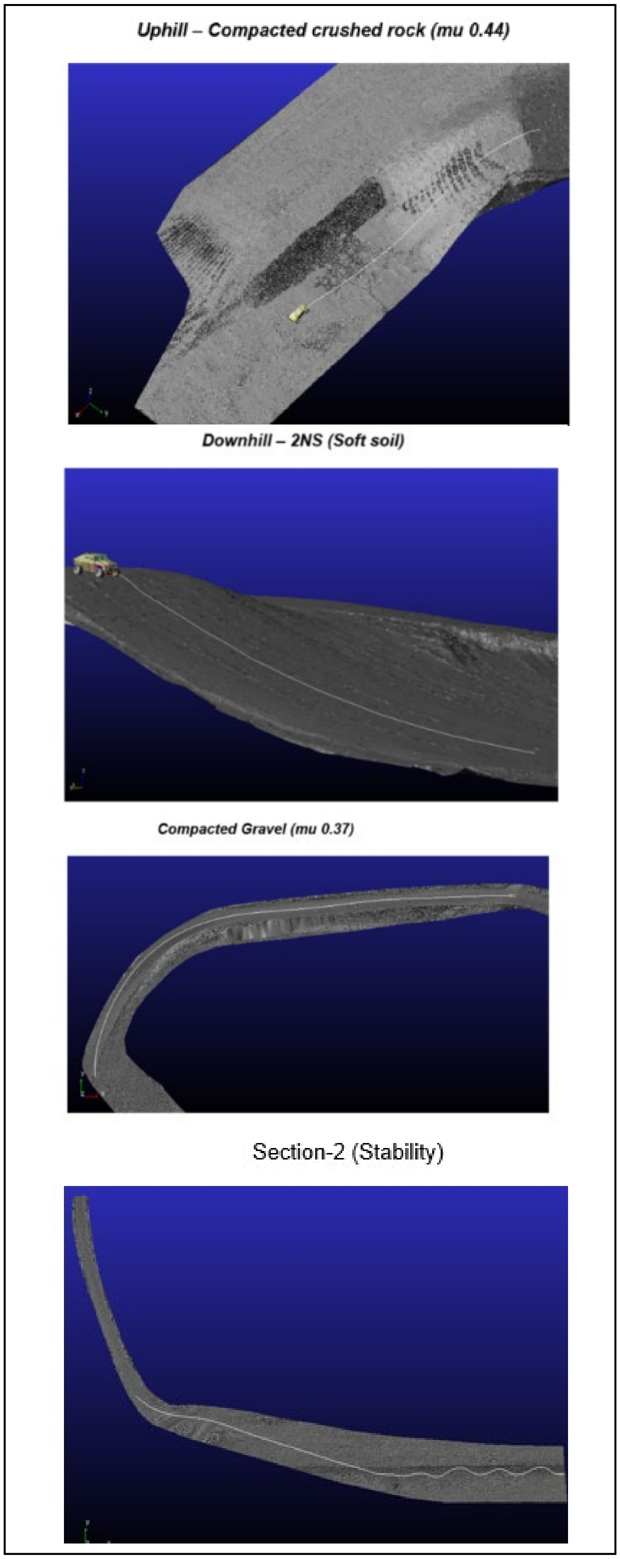

Figure 2: Virtual Terrain from LIDAR data

The figure below shows the vehicle performance (speed) comparison of a terrain traverse (with combination of Gravel & Soft Soil) to NG-NRMM test results.

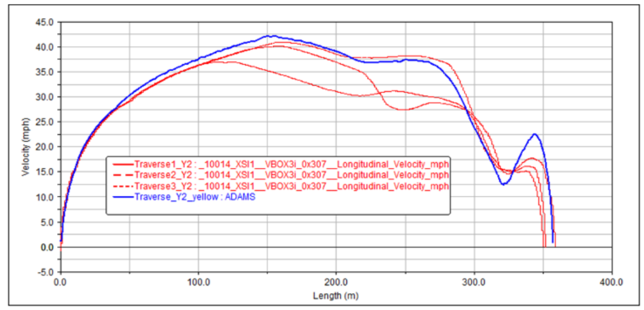

Figure 3: Terrain Traverse, Vehicle Performance-speed (Test vs ADAMS)

In order to study the capability of both the simple and complex terramechanics methods and their ability to predict the mobility of the vehicle, a segment from the traverse with wet fine-grain sand (FGS) was simulated.

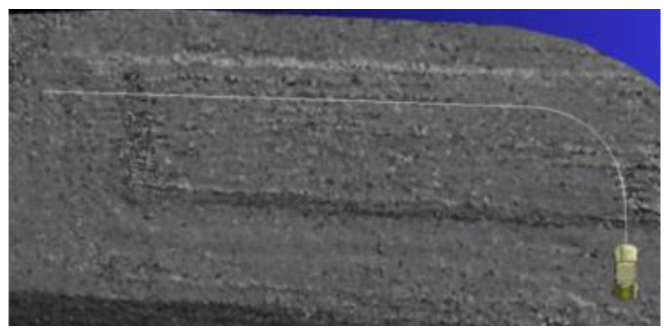

Figure 4: Virtual Terrain Wet fine grain sand (FGS)

This traverse section was simulated using both the Bekker-Wong simplified terramechanics method and the DEM (Discrete Element Method) complex terramechanics method.

The predicted rate of acceleration on a wet fine-grain sand for the traverse segment using the simple terramechanics approach is compared to the test in the figure below. Vehicle speeds are not compared here as test and simulation have different speeds at entry point to the wet soil. Hence only the acceleration rates are compared for performance evaluation.

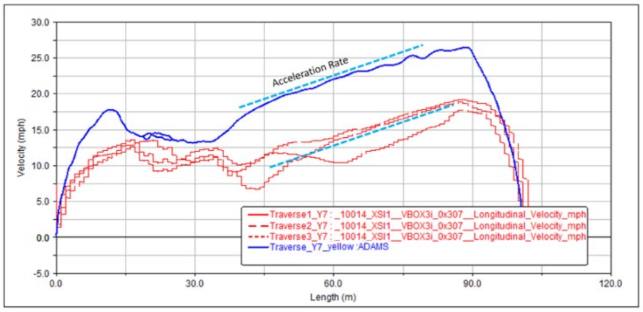

Figure 5: SimpleTerramechanics, Vehicle Speed (Test vs ADAMS)

In contrast with the analytical formulations of bulk properties used by simplified terramechanics, complex terramechanics represent the material via a collection of interacting particles with simple shapes (typically based on circles and spheres). The contact properties acting between the particles are represented using a variety of spring/damper/friction formulations, allowing the representation of actual soil properties. These model parameters can be difficult to obtain by direct physical measurement. Indirect methods of parameter determination are often necessary. Among them, the trial-and error approach has been used successfully.

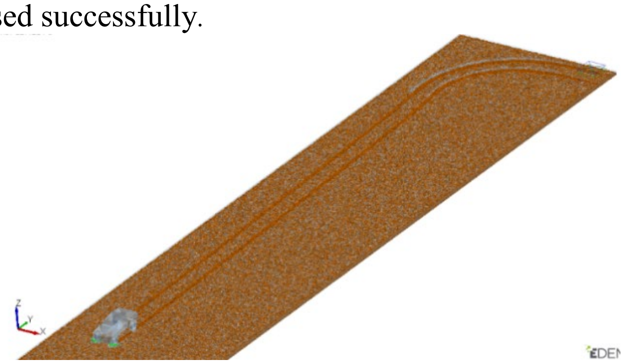

Figure 6: Complex Terramechanics, DEM Model representation of Wet Fine grain sand (FGS)

MSC Adams™ was coupled with EDEM® for dynamic simulations with deformable soil interaction. Coupling DEM with MBD will transfer transient loads from the geo-materials model into the full vehicle multibody model, and pass part displacements back to the DEM solver. The predicted vehicle velocity for the traverse segment using the MSC Adams™ and EDEM® co-simulation approach is compared to the test.

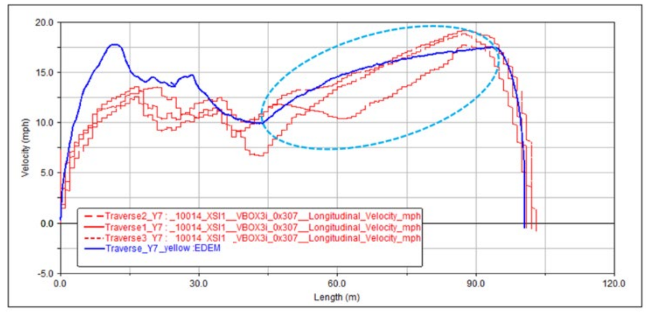

Figure 7: Complex Terramechanics, Vehicle Speed (Test vs ADAMS EDEM cosimulation)

MSC Adams™ can predict the maximum speed throughout each terrain, subject to the vehicle limits (acceleration, braking, handling and absorbed power). The resulting vehicle capability (maximum speed) predictions from MSC Adams™ simulations for various grades, and soil types can be generated and provided as inputs to the mapping application.

6. Mobility Mapping

Making use of the mobility assessments that are generated through simulations for vehicle characterization events can offer insight into how the vehicle may perform in specific geo-locations. To aggregate this information into a route planning tool, the Luciad Lightspeed technology was used to provide visualization of the terrain and the associated vehicle's predicted mobility characteristics.

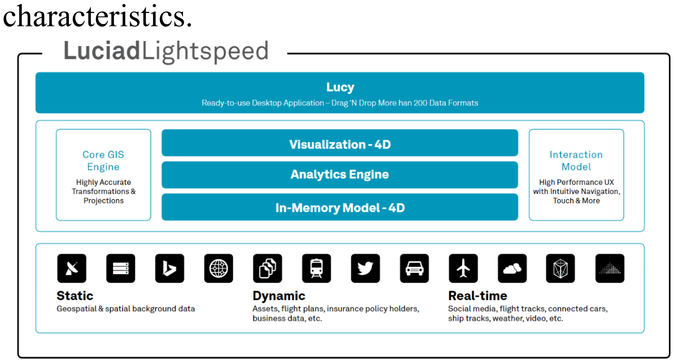

Figure 8: Luciad's Desktop and On-board Solution

The inputs to the mapping application included geospatial layers for soil type, elevation, grade, and aerial imagery. In addition, the vehicle capability (maximum speed) for various grades, and soil types, was generated through MSC Adams™ simulations and provided in table format. Given this information, the application provides two mobility-focused capabilities:

- **Speed Made Good Map**: The soil, grade and vehicle performance data were combined to visualize the maximum vehicle speed throughout the map
- **Route Planning:** Given selected route endpoints, the application will compute an optimal cross-country route, along with elapsed time and distance traveled.

This mapping toolkit provided the foundation for advanced geospatial analytics applications, and allowed the rapidly develop high performance location intelligence applications. Various software components and connectors were used to fuse, visualize and analyze geospatial data associated with the Keweenaw Research Center test area. This included static data, maps, satellite imagery, weather data (moisture content) and terrain elevation in a defined region, resulting in different geodetic references and map projections

6.1. Speed Made Good Maps

A framework for vehicle analysis methods accounting for the variability of the terrain and soil properties was successfully demonstrated in previous sections, using rigid roads as well as simple or complex terramechanics. This capability for evaluating the vehicle under multiple soil and grade conditions allows broad characterization of the vehicle performance throughout a given terrain. Provided with terrain details, the vehicle properties can be projected onto a map to visualize the vehicle capabilities. This map, showing the maximum obtainable speed at each location is typically referred to as a Speed Made Good map. A map like this facilitates operational mission planning, as it can clearly indicate areas where soil or grade will contribute to or degrade vehicle mobility. The workflow associated with creation of this type of map is outlined in Figure 9.

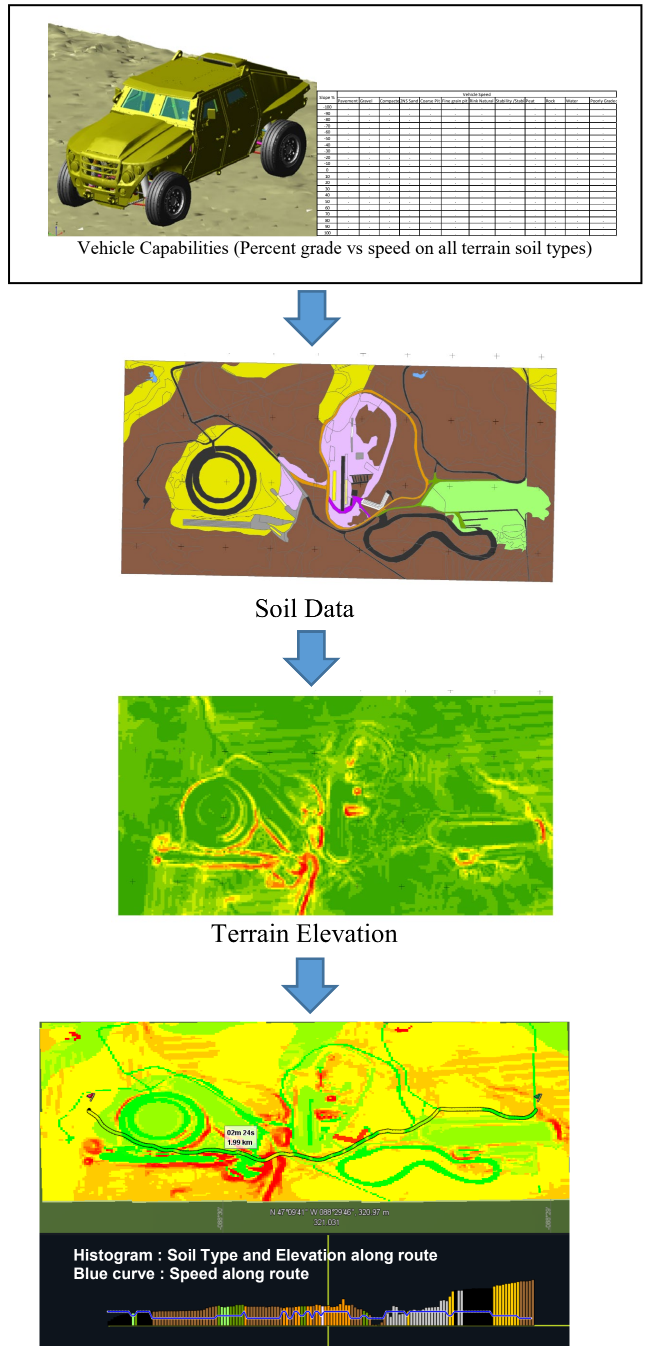

Figure 9: Workflow to generate speed made good map used for route planning

6.2. Route Planning

The application developed for this project predicts an optimal route that accounts for both the soil and the effective grade along the path. This tool has been developed to illustrate the capability of modern geospatial software in a mobility context and is not expected to provide a comprehensive mobility assessment. For effective operational use, it would be necessary to incorporate significant additional logic into the tool, including side-slope characteristics (e.g., traversing a slope was treated the same as flat), RMS limitations, and obstacle information. Beyond this, the Luciad framework can facilitate integration of additional information such as line-of-sight considerations and real-time sensor inputs.

7. Conclusions

Vehicle mobility assessment can effectively make use of MBD simulations to predict the capability of a vehicle to traverse various terrains and soil types.

Improved terramechanics models are available through a Discrete Element Method approach (DEM) and demonstrates a higher level of fidelity when compared to vehicle tests with the traditional simple terramechanics calculations. This fidelity has been demonstrated with the predicted traction behavior for drawbar pull test. These methods are quite compatible with the MBD approach used in this paper, and have been demonstrated by others to be effective for both wheeled and tracked vehicles.

Using the results of mobility simulations to create interactive maps that integrate vehicle capabilities, GIS data, soil types and other terrain information, has been demonstrated, and has the potential to facilitate real-time route planning

8. REFERENCES

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[4] B. Edwards, "Co-Simulation of MBD Models With DEM Code to Predict Mobility on Soft Soil", Proceedings of 2018 GVSETS, Novi, Michigan 2018.