

Simulating the Mobility of Wheeled Ground Vehicles with Mercury

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ABSTRACT

Mercury is a high-fidelity, physics-based object-oriented software for conducting simulations of vehicle performance evaluations for requirements and engineering metrics. Integrating cutting-edge, massively parallel modeling techniques for soft, cohesive and dry granular soil that will integrate state-of-the-art soil simulation with high-fidelity multi-body dynamics and powertrain modeling to provide a comprehensive mobility simulator for ground vehicles. The Mercury implements the Chrono::Vehicle dynamics library for vehicle dynamics, which provides multi-body dynamic simulation of wheeled and tracked vehicles. The powertrain is modeled using the Powertrain Analysis Computational Environment (PACE), a behavior-based powertrain analysis based on the U.S. Department of Energy's Autonomie software. Vehicle-terrain interaction (VTI) is simulated with the Ground Contact Element (GCE), which provides forces to the Chrono-vehicle solver. The driver model implements an array of tests for evaluating vehicle mobility performance. With these physics submodules, Mercury can simulate a variety of performance tests such as ride quality, maximum shock, sand slope climbing, VCI, acceleration tests, and many others. Additionally, the open, modular framework of Mercury makes the extension of the software to new tests and physics domains fast and easy.

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INTRODUCTION

Mercury is a software application for simulating the performance of wheeled and tracked ground vehicles in engineering-level performance tests such as slope climbing and max speed. The Mercury software is one product that is being developed as part of the Computational Research and Engineering Acquisition Tools and Environments for Ground Vehicles (CREATE™-GV) toolset; the result collaboration between the US Army Engineer Research and Development Center (ERDC) and the Tank Automotive Research, Development, and Engineering Center (TARDEC). Mercury combines multiple physics models for vehicle subsystems into a single, integrated simulation tool that captures the interactions of vehicle dynamics, powertrain performance, and vehicle-terrain interaction.

Mercury includes a set of several applications, each one consisting of different combinations of physics models, allowing users to select the appropriate combination of models for their interest. In addition, Mercury allows user to modify vehicle parameters such as mass, suspension stiffness, wheelbase, powertrain capability, and tire shape to evaluate the influence of these parameters on overall vehicle performance.

In this paper we will present the modular framework and component models of Mercury, as well as the results of several performance simulations.

MERCURY FRAMEWORK AND COMPONENTS

Mercury features a modular framework that allows new physics modules to be rapidly integrated into the code, as well as allowing new simulations of performance tests to be created without altering the core code. This section discusses the modular framework as well as the physics modules that are integrated into this framework.

Framework

Mercury provides a framework for coupling physics simulations of vehicle dynamics, powertrain, vehicle-terrain interaction (VTI), and driver dynamics into a modular, integrated, cosimulated application. In order to achieve this, Mercury uses a hierarchal framework and a set of pre-defined data structures and base classes ("class" being a program-code-template in object oriented programming) from which new physics modules can be developed.

Clients

Physics modules in Mercury are referred to as *Clients*. There are four types of clients: Vehicle, VTI, Powertrain, and Driver. Each of these *Client* classes must inherit from the appropriate Mercury base class and must have an update method that takes certain data structures as input and returns specified output. More details on the structure of these classes can be found in the Mercury developer's guide.

Simulations

In Mercury, a *Simulation* is a collection of clients. While there are a limited number of client types, there are a variety of ways in which they could be coupled to form a Simulation. As with the clients, Mercury provides a base class that defines the methods and data that must be associated with a Mercury simulation. In particular, the Run() method is where the client communication and physics updates take place. Having multiple simulations allows the clients to be coupled together and modified in unique ways to meet the demands of certain tests. For example, certain tests, such as the static axle-load test, do not require a driver or powertrain client. Additionally, the ability to add new simulations allows Mercury to be extended with new clients (for example, an active suspension system) without modifying existing capability.

Tests

A *Test* in Mercury corresponds to a real test that could be performed on a vehicle in a field experiment. A test in Mercury generally takes a "Simulation" as its input. However, there is no base class for a Mercury test and the inputs could be flexible. The role of a test is to define the inputs to the *Simulation* such as the desired vehicle speed and path, and process the logged simulation data to produce a test output. For example, in the Max Speed test, the *Test* code would scan the simulation data log for the maximum speed achieved by the vehicle.

With this hierarchical framework, extending Mercury with new tests is generally fast and does not require modifications too the core code base.

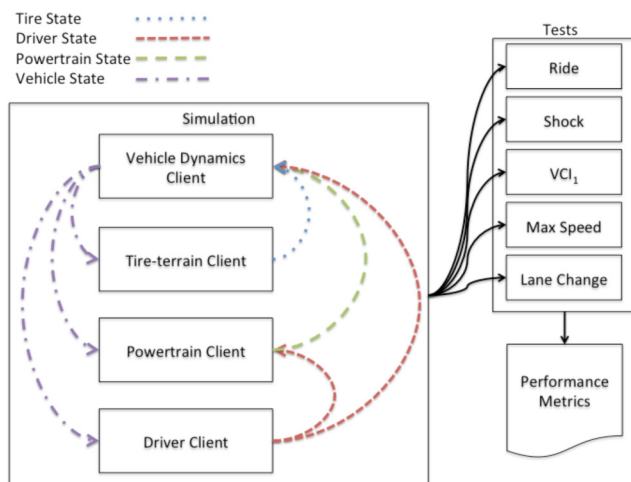


Figure 1. Mercury framework diagram.

Powertrain

The Powertrain Analysis and Computational Environment (PACE) [1] is the primary powertrain simulation library in Mercury. Developed by researchers at Mississippi State University, PACE is a C++ based adaptation of the Department of Energy's Autonomie code [2].

Multibody Dynamics

Mercury uses ProjectChrono to simulate vehicle dynamics. ProjectChrono is a general purpose multibody dynamics library that is modular, open-source, and features a wide range of functionality for applications ranging from vehicle dynamics to fluid flow [2]. ProjectChrono features a template vehicle dynamics library that allows users to modify vehicle properties through simple inputs and rapidly create complex vehicle models. In particular, there are templates for several common suspension types such as solid-axle, multi-link, McPherson strut, and double wishbone.

The templates can be easily modified and combined with templates for steering mechanisms and wheelbase configurations to quickly generate new vehicles. For example, the vehicle template lists several items like the mass and inertia properties of the vehicle, the location of the center of gravity, and the hardpoints for the suspension assemblies. All these can be modified through the text file. The suspension assemblies themselves are defined in separate template files, and properties like the spring and damping response can be defined and adjusted easily.

Tire / Soil

An important feature of off-road mobility is mobility in soft soil. Mercury simulates soft soil mobility with the Ground Contact Element (GCE) software library - an empirically derived library that models the traction and resistance forces produced at wheel elements. While the basic mobility characteristics of the GCE are presented in [3], many of the specifics of the implementation have not been published. Therefore, we present the GCE equations for cohesive soil in the Appendix. The GCE uses a different set of equations for granular material, which will be presented in future work.

MERCURY TEST RESULTS

Three different tests with three unique vehicles were simulated in Mercury and compared to experimental results for these vehicles. The tests focus on different aspects of the integrated Mercury simulation, although all modules are engaged for each test. The max speed test highlights the powertrain simulation in Mercury, the shock test highlights the vehicle dynamics, and the VCE test highlights the soft soil simulation capability in Mercury.

The properties of the different vehicles tested in Mercury are listed in Table 1. The M1152 is an open backed, up-armored HMMWV, while the M1025 is a closed back armament carrier without up-armoring. The third HMMWV variant, labeled Mxxxx, is a non-production heavy HMMWV variant.