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Overview of cold regions mobility modeling at CRREL

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Abstract

Over the last several decades, the Cold Regions Research and Engineering Laboratory (CRREL) has extensively tested and analyzed issues related to vehicle performance in winter. Using this knowledge and the experimental database, models were developed to capture the important elements for cold regions mobility performance. These models span a range of resolutions and fidelities and include three-dimensional finite element models of tire–terrain interaction, vehicle dynamics models of vehicles on winter surfaces, semi-empirical cold regions algorithms for winter performance within the NATO reference mobility model (NRMM), all-season vehicle performance in force-on-force war-gaming simulations, and vehicle–surface interaction for real-time vehicle simulators. Each of these types of models is presented along with examples of their application.

Keywords: Vehicle; Terrain; Winter; NATO reference mobility model; Snow; Ice; Soil; Freeze; Frost; Thaw

1. Introduction

Vehicle performance in winter conditions is largely determined by the low friction and deformable surface material that affects vehicle traction, motion resistance, handling, and maneuvers. The Cold Regions Research and Engineering Laboratory (CRREL) has been studying the impact of winter on vehicle mobility for many years.

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Within the last decade, a concerted effort has gone into translating this knowledge base into computer models to help predict vehicle mobility in cold regions. Several types of models have been developed and are briefly presented:

1. Tire–terrain finite element modeling for cold regions terrains.
2. Variable friction tire model for vehicle dynamics simulations.
3. High-fidelity tracked and wheeled vehicle dynamics modeling for seismic signature simulations.
4. Algorithms for cold regions mobility performance within the NATO reference mobility model (NRMM).
5. Vehicle speeds under winter conditions in war-gaming simulations.
6. All-season, cross-country mobility for real-time vehicle simulators.

2. Finite element tire–terrain modeling

Tire performance in winter is important for passenger vehicles operating on snowy roads, as well as to the many industrial (agriculture, forestry, mining, construction), military, and recreational vehicles that are used for off-road operations in all weather conditions. The desire to incorporate theoretical mechanics into off-road vehicle performance prediction has generated great interest in applying numerical modeling techniques to simulate the interaction of the tire and terrain. Therefore, a full three-dimensional model simulating a tire rolling over deformable terrain was developed. The project consisted of three major tasks [1,2]:

- Evaluating tire modeling techniques that would be suitable for use in simulating a tire rolling on deformable terrain.
- Generating constitutive models for snow and other terrain materials for cold regions.
- Developing a complete three-dimensional model that combines the tire model with a model of deformable terrain.

2.1. Tire models

To apply a tire model to deformable terrain, a model is needed that is efficient yet accurately portrays the tire's structural behavior. Specifically, an accurate model of the contact patch is critical for simulating the impact of deformable terrain on tire performance. Models commonly used for designing tires predict deformation of the complete tire, including the interaction of the internal components. However, as our concern is only the deformation as it relates to the contact region and the tire's ability to roll across a deformable surface, simpler tire models can be employed for better computational efficiency. To this purpose, four types of tire models were evaluated for suitability to rolling on deformable terrain: