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Sustainable non-automotive vehicles: The simulation challenges

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ABSTRACT

Simulation is a well-established and effective approach to the development of fuel-efficient and low-emissions vehicles in both on-highway and off-highway applications.

The simulation of on-highway automotive vehicles is widely reported in literature, whereas research relating to non-automotive and off-highway vehicles is relatively sparse. This review paper focuses on the challenges of simulating such vehicles and discusses the differences in the approach to drive cycle testing and experimental validation of vehicle simulations. In particular, an inner-city diesel-electric hybrid bus and an ICE (Internal Combustion Engine) powered forklift truck will be used as case studies.

Computer prediction of fuel consumption and emissions of automotive vehicles on standardised drive cycles is well-established and commercial software packages such as AVL CRUISE have been specifically developed for this purpose. The vehicles considered in this review paper present new challenges from both the simulation and drive-cycle testing perspectives. For example, in the case of the forklift truck, the drive cycles involve reversing elements, variable mass, lifting operations, and do not specify a precise velocity-time profile. In particular, the difficulties associated with the prediction of productivity, i.e. the maximum rate of completing a series of defined operations, are discussed. In the case of the hybrid bus, the standardised drive cycles are unrepresentative of real-life use and alternative approaches are required in the development of efficient and low-emission vehicles.

Two simulation approaches are reviewed: the adaptation of a standard automotive vehicle simulation package, and the development of bespoke models using packages such as MATLAB/Simulink.

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1. Introduction

Accurate simulation of vehicle powertrains is an essential part of the study into reducing fuel consumption and emissions of on- and off-highway vehicles. The ability to simulate vehicles on a component level allows for models of complex architectures to be built and validated. Once validated, these models can then be used to predict how changes to the vehicle's powertrain affect fuel consumption.

An accurate vehicle model leads to several advantages from a research and development viewpoint; the most important of which is a reduction in the amount of physical prototyping, as changes to powertrain components can be simulated based on physical data which may be obtained from manufacturers or bench testing of individual components. This reduction in whole-vehicle physical prototyping leads to an associated reduction in development times and costs, and allows several components to be investigated in a virtual environment; the most suitable may then be selected for installation and testing on the real vehicle.

Validation of these models may be carried out by comparing the performance of the whole vehicle, or individual systems within it, to experimentally-obtained data. This usually takes the form of drive-cycle analysis, where an instrumented vehicle is driven on a pre-defined course and parameters such as vehicle speed, driver inputs, and individual component data such as pressure, speed, position, etc. are recorded. The simulated vehicle can then be compared to the experimental data, thus highlighting areas where the model must be improved.

A properly validated model allows the vehicle designer to then investigate how changes to the vehicle or its powertrain affect parameters such as fuel consumption and emissions by including these changes in the simulation and re-running the validated drive cycle.

Within the automotive sector, simulation has been a widely used tool for decades, mainly stemming from the simulation of engines and their application to automotive vehicles [1–4]. This has allowed advanced models to be built, while a comprehensive database of literature and vast array of experimental data has allowed these models to be easily validated and compared. The amount of literature available also goes some way to defining a standard approach to modelling automotive vehicles.

However, within the non-automotive sector, which in this paper will include buses, trucks and off-highway vehicles, the development of advanced simulations has been much more recent; therefore the volume of published literature is severely limited. This makes it all the more difficult for the non-automotive vehicle designer to use a previously tested approach to develop validated simulations.

This paper begins by outlining the approach taken in a number of automotive simulations: the choice of software environments available, the approach taken and the challenges encountered. This leads on to a discussion of the various approaches taken to adapt these automotive models to non-automotive applications, and how bespoke models have been created for specific scenarios. The simulation of hybrid vehicles is discussed throughout both automotive and non-automotive sections, and in particular the suitability of various software packages in adapting to the challenges associated with hybrid vehicle architecture is discussed.

The paper focuses on the simulation of two particular cases studies in the non-automotive sector: hybrid city buses, and forklift trucks, both of which provide numerous simulation challenges. The conclusions of the paper aim to offer the reader a summary of the simulation approaches taken in the various applications discussed and some of the obstacles that can be expected when simulating non-automotive vehicles. This allows the reader to take a more direct approach to developing a simulation strategy depending on the application under study.

2. Automotive simulation

Simulation of automotive vehicles is a well-established field of study and there is a wealth of commercial and open-source software available [5]. This section discusses some of the main packages available and shows how they have been applied to automotive simulations. The suitability of each package to simulate hybrid vehicles will also be discussed in each subsection where literature on the subject was available.

2.1. Simulation packages

2.1.1. AVL CRUISE

This commercial automotive simulation software allows the user to create a graphical model of the vehicle, hiding from view all but the main mechanical connections and modules. Blackmore et al. [6] used CRUISE to create a model of an automotive vehicle. The basic vehicle model, including tyres, brakes, differential, transmission, engine, and a driver model, was constructed as shown in Fig. 1.

This model was then compared to one of a hybrid vehicle where CRUISE was able to produce detailed analysis of battery state-of-charge and showed instantaneous battery consumption throughout the 'Japanese 10–15' drive cycle. It also allowed a detailed study of battery technology to be carried out, with three different battery types used in the vehicle model (NiMH, Lead-Acid and Li-ion).

A similar parametric study was carried out by Oh et al. [7], who used CRUISE to model SI (spark ignition) and CI (compression ignition) automotive vehicles over seven types of automotive drive cycle. The authors mentioned CRUISE's prediction of CO_2 emissions is not based on maps, and instead it assumes fuel is completely combusted. Therefore, the emissions rate is related to the type of fuel used and the calculated instantaneous rate of fuel burned.

The results of this paper show excellent correlation between the simulations and experimentally obtained data. Parameters such as engine speed were predicted very accurately on all the drive cycles investigated, as were fuel consumption and CO_2 emissions. In addition, the authors were able to perform a comprehensive parametric study of each vehicle analysed and

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