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METHODOLOGY FOR THE OPTIMIZATION OF AN ENERGY EFFICIENT ELECTRIC VEHICLE

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ABSTRACT

The future of transport is foreseen in electric vehicles. Despite many advantages, the wide usage of this type of vehicles is limited by a few shortcomings. One of the most serious limitations of such vehicles is low range, which in combination with the poor infrastructure of the charging station is a big limitation. The solution to the problem of low range of these vehicles is implemented, among others, through the continuous development of battery technology or the development of other automotive sources of electric energy (fuel cell stacks). Another way to increase range is to reduce the energy consumption of electric vehicles. This last issue is a special challenge. Designing electric vehicles is a complex issue, especially in the context of reducing their energy consumption. The number of factors affecting energy consumption is significant and covers a range of multidisciplinary issues. The paper describes the method of optimization of an electric vehicle that allows for a significant reduction of the energy consumption of the designed vehicle taking into account multidisciplinary optimization. This method has been implemented to design an electric vehicle designed for energy-efficient vehicles competition.

Keywords: energy-efficient vehicle, multidisciplinary optimization, model-based design, model-based optimization, numerical simulation, Shell Eco-marathon.

INTRODUCTION

Typically, vehicle design takes place in several stages from the conceptual phase through the preliminary design to the technical project at each stage there are strict specific phases of partial optimization of individual subsystems or the entire system. The multidisciplinary nature of issues that must be taken into account in designing hinders the overall optimization leading to the inevitable compromises realized in individual stages. The changes that take place in the next steps in the course of designing are not studied continuously in the direction of their impact on optimization.

THE METHOD OF DESIGN AND OPTIMIZATION OF THE VEHICLE

The proposed method uses a completely different approach using a well-known design method based on the concept of Model-based design (Skoberla, 2017). The Model-based design assumes the development of numerical simulation models of the designed multidisciplinary system from the earliest stages of design and development of this model in accordance with the increasing level of detail of the designed system along with the development of the system. In Model-based design, the system model is at the center of the

development process, from developing requirements, through design, implementation and testing. At each stage of design, the model is a reflection of the state of knowledge about the designed system. This is especially important for complex systems whose operation is difficult to predict. Thanks to the simulations carried out on the model, we can determine whether the system development is going well. The simulation shows if the model works correctly. The model is also used to determine the basic design features of the designed system.

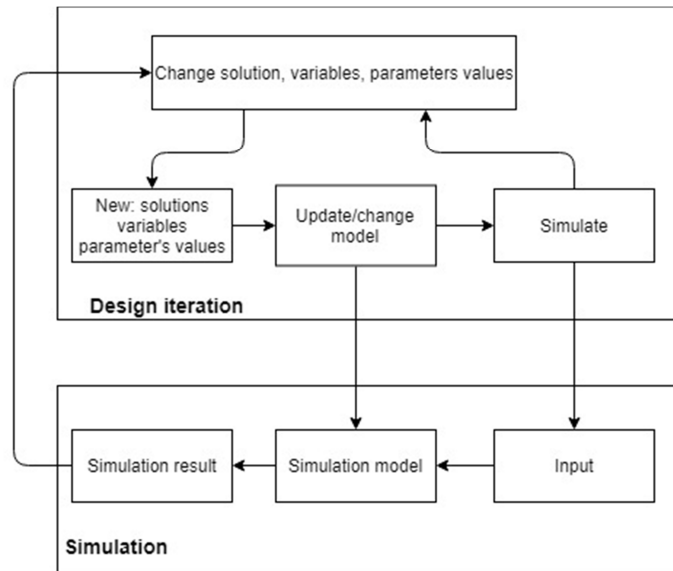


Fig. 1 - Model-Based Design diagram

In addition to the well-known Model-based design method, an intensive application of optimization methods has been proposed, thus the strictly defined criteria for energy consumption (Skarka, 2015) while driving allow not only to assess at each stage of the development of the electric vehicle project what effect the proposed current design features have on the energy consumption of the vehicle but also to find a set of features and solutions optimal for defined assumptions and limitations (Tyczka, 2016), (Targosz, 2013).

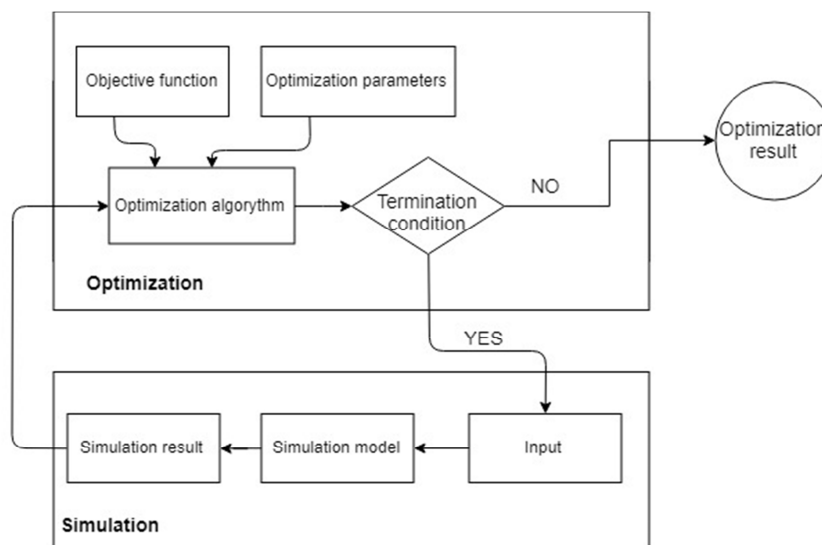


Fig. 2 - Model-Based Optimization diagram

Additionally, in combination with the tests on the real object using the inverse model and optimization methods, it was possible to verify the design parameters that were determined during the design process with an increased degree of uncertainty.

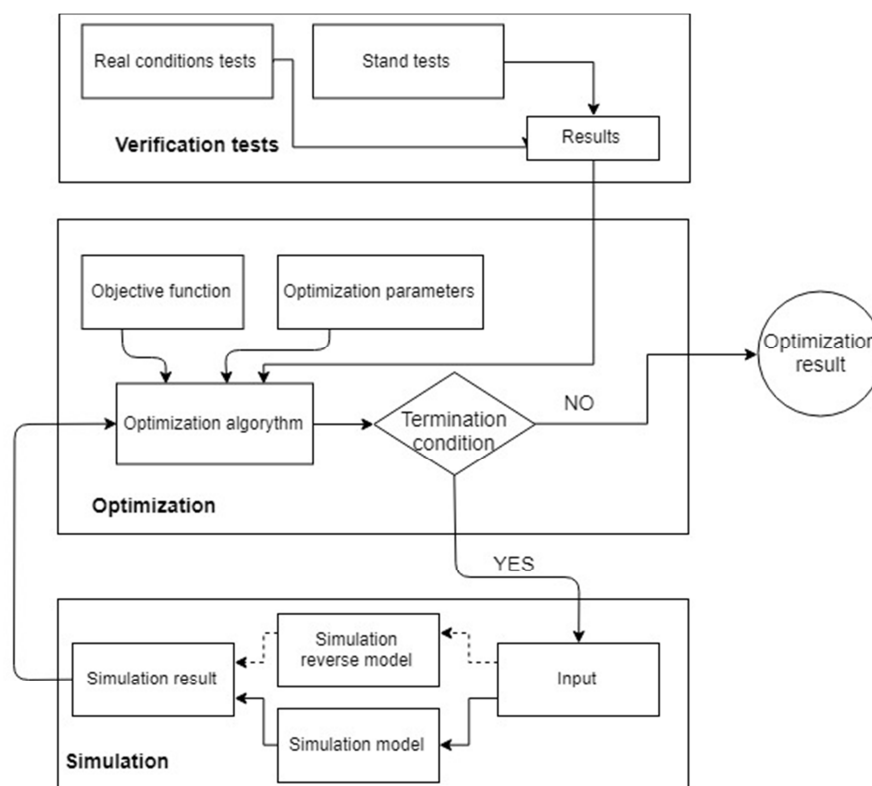


Fig. 3 - Model-Based Optimization diagram

The problem of the solution of the optimization task is significantly complicated when the optimization issue is a multidisciplinary issue and requires the application of many different specialist teams from various fields (Multi-objective Design Optimization) to solve the problem. Apart from the organizational and logistic problems connected with the cooperation of various organizational and often remote units operating in various social and cultural conditions, and remaining only with the substantive assessment of the task itself, there are many problems with such development works. Some of these problems are:

- Identification of requirements and constraints defined by customer is often difficult,
- The impact of non-technical aspects when defining objectives and criteria, especially for consumer goods, essentially reduces the sense of optimization itself, because ultimately non-measurable factors such as eg aesthetics of the product can have a decisive impact on the development of the product itself and product sales volume,
- complex dependencies and couplings between the optimization tasks themselves, usually consisting of local and global problems, make it difficult to identify and specify the task,
- specific computer tools that hinder the task's integration are used in solving optimization tasks,
- the complexity of the task requires the use of specialized equipment of high numerical processing capacity.

MDOs have evolved into a separate field and now a number of methodologies for solving such optimization problems are proposed (Bil, 2015). Parallel to the methods and methodologies (Neumaier, 2004), (Weise, 2009), there are proposed environments for solving multidisciplinary optimization problems (Bil, 2015) (Sobolewski, 2015) such as FIDO, iSIGHT, LMS OPTIMUS, DAKOTA. They allow for easier integration of independent software usually used for modeling and simulation in structural design, aerodynamics, aeroelasticity, thermodynamics, electrical design etc. Despite these facilities, the solution usually requires intensive integration of activities in various fields and environments with a large involvement of various specialists. The challenge is simplification allowing for obtaining satisfactory results while reducing the resources (Liu, 1989) necessary to solve and separating in time and making the tasks of specialized optimization and project activities independent. This is especially useful for the development of specialized vehicles built for electric racing of energy-efficient vehicles.

From practice and experience so far, four factors have a decisive influence on reducing energy consumption: aerodynamic characteristics of the vehicle, its weight, drive and power system characteristics, and driving strategy. Other factors related to the construction of the vehicle, even if they have an impact on energy consumption, can be solved as separate optimization issues, eg characteristics of the vehicle suspension.

During the development works on electric vehicles competing in the electric energy-efficient racing competition, a methodology for vehicle optimization has been proposed, allowing for a significant reduction of energy consumption. The methodology includes an iterative approach consisting of:

- development of vehicle simulation model and MBD environment and conducting simulations allowing for assessment of individual proposed solutions at the concept construction stage,
- identification and construction of partial simulation models using various methods, eg through stand tests
- conducting simulation and optimization of MBDO at various stages of development of structures that help identify the impact of various factors on energy consumption and determining the design features of the vehicle,
- development of an exact optimization simulation model of the vehicle in the race environment and its verification through vehicle testing on the road,
- development of a racing strategy based on the results of optimization,
- using the reverse simulation model to verify the results of construction works and the tuning of the model.

USE CASE

The method has been applied to the design and development of three existing vehicles for the purposes of the Shell Eco-marathon race:

- MuSHELLka - Battery Electric Prototype category vehicle,
- Bytel - a vehicle of the Urban Concept BatteryElectric category
- *Hydro*GENIUS - a vehicle of the UrbanConcept Hydrogen category

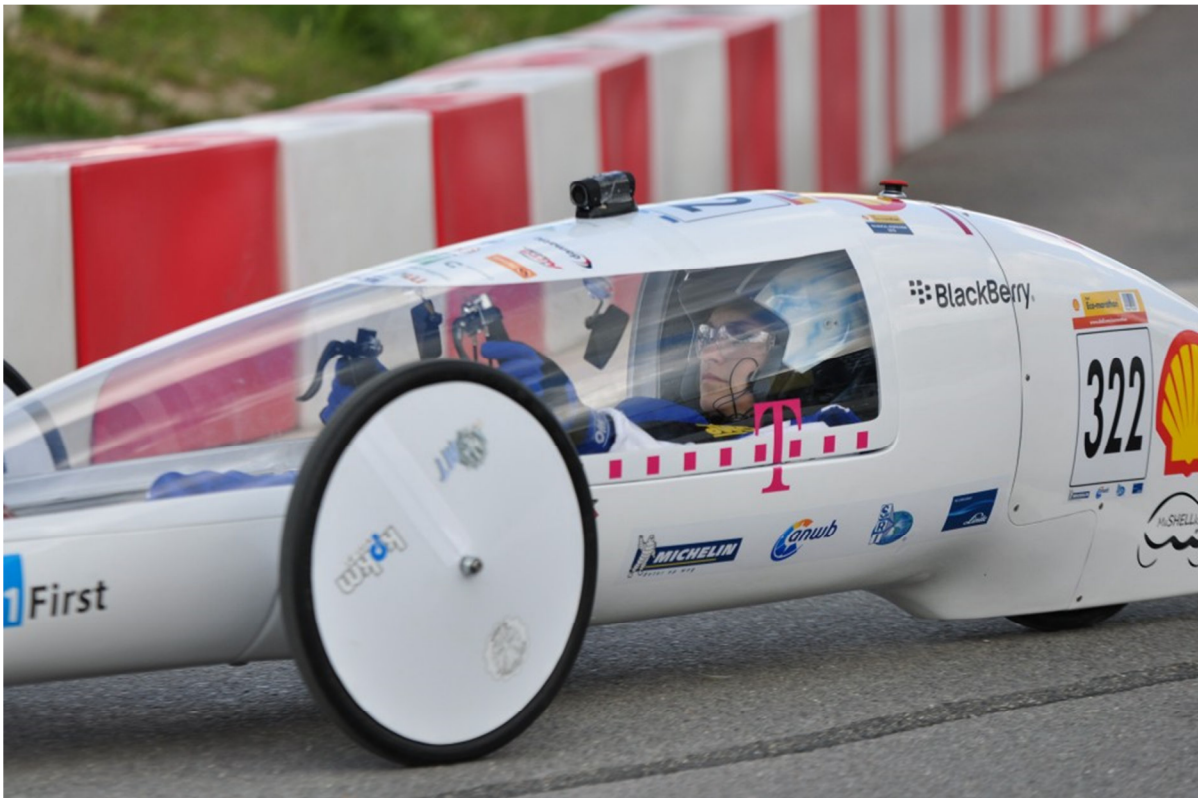


Fig. 4 - MuSHELLka electric race vehicle



Fig. 5 - HydroGENIUS electric race vehicle

Simulation models of the vehicles themselves are developed for vehicles, and the exact simulation model of the racetrack is ultimately being developed. The models have a modular design so that it is possible to improve this model as easily as possible.

The main modules of the simulation model developed in the MATLAB/Simulink environment are as follows (Skarka, 2015):

- vehicle,
- racetrack,
- external conditions,
- strategy,
- movement resistance,
- movement parameters/results

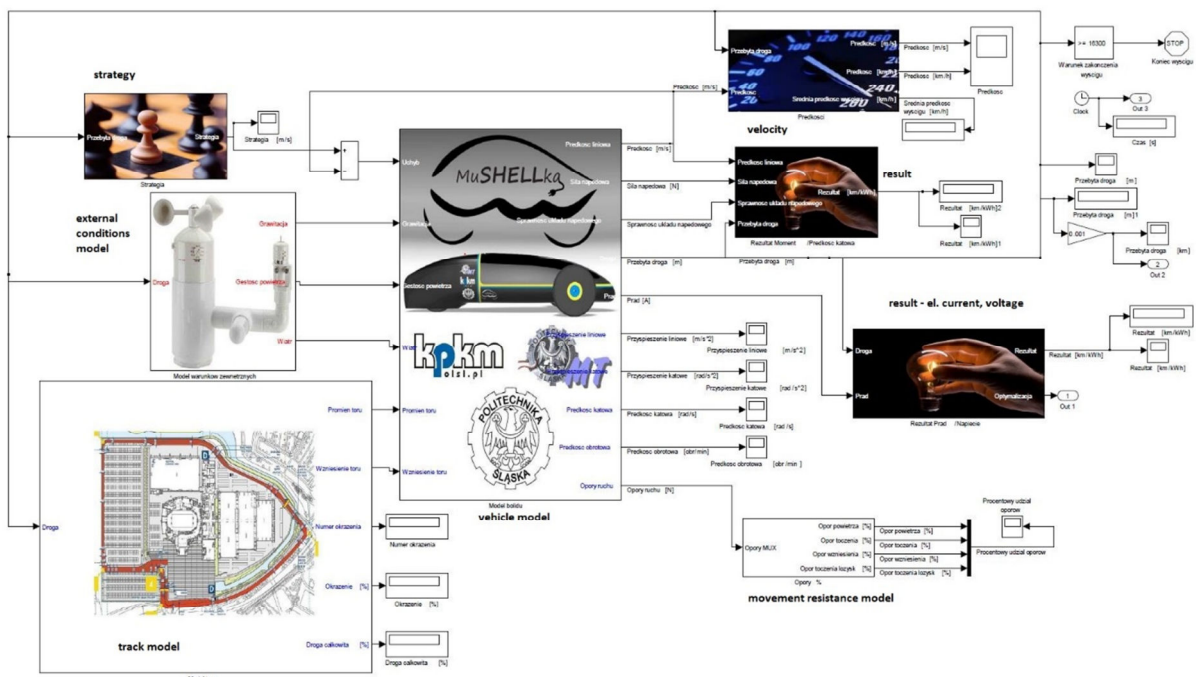


Fig. 6 - Framework of the main model for MuSHELLka for Model-Based Design and Optimization approach

The application of model simulation from the very beginning, even at the initial stage of the concept in the design process of the MuSHELLka vehicle allowed to direct limited design resources to design components having the greatest impact on the result and the initial determination of the features of these components. Subsequently, during the development of the project and the simulation model, simulation calculations were carried out whose results allowed to determine the final constructional features (Wąsik, 2016). Next, the optimization calculations were made towards developing the driving strategy during the race, the initial results from the strategy indicated by the drivers and the application of the optimization calculations were characterized by about twice as much energy consumption. Subsequent work included verification of individual constructional features using MBDO methods and road test results. The method was used to determine the aerodynamic characteristics of the

vehicle (Skarka, 2014). The results of calculations have been confirmed in the wind tunnel tests. For faster incorporation of results in the geometric model of the structure, advanced methods of Generative Modeling (Jałowiecki, 2016) were used.

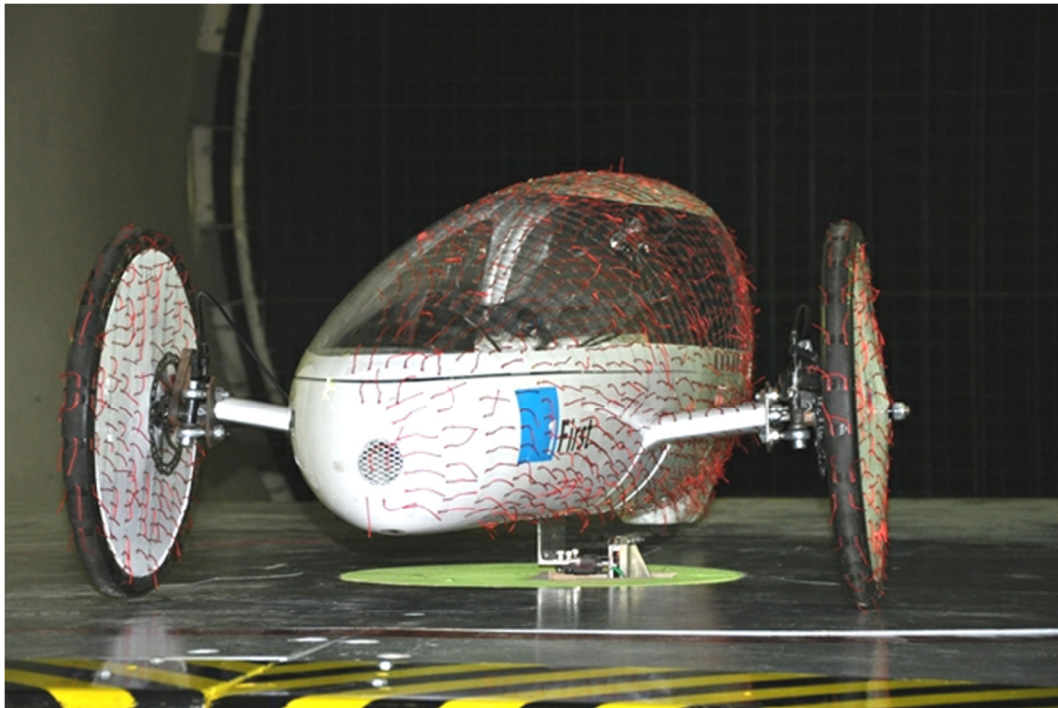


Fig. 7 - Aerodynamic tests of the vehicle - thread flow visualization

RESULTS AND CONCLUSIONS

The proposed design method involving a combination of Model-based Design and Model-based Optimization has been used in the design of three electric racing vehicles that successfully competed in Shell Eco-marathon (SEM, 2018), obtaining in 2016 the 2nd place in the UrbanConcept class of vehicles with the Hydrogen Fuel Cell Stack power source. In addition, the use of the inverse model was verified in the calculation of aerodynamic characteristics, obtaining better results than in CFD (Computational Fluid Dynamics) methods (Skarka, 2014). The current work focuses on improving the detailed model of power sources and, above all, the complex power source that is Hydrogen Cell Stack integrated with supercapacitors. With such power sources with complex characteristics, the use of MBDO methods allows for a significant reduction of energy consumption while driving a vehicle.

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