SURROGATE-BASED OPTIMIZATION OF THE NOSE SHAPE OF A TRAIN SUBJECTED TO CROSS-WIND

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People have never traveled as much as over the last decade and, in this situation, the importance of trains has notably grown because of its energy efficiency. More mobility involves an increase in both the train cruise speed and lightness, and these requirements directly influence the stability and the ride comfort of the passengers when the train is subjected to a cross-wind. Thus, cross-wind stability plays a very relevant role among the aerodynamic objectives to be optimized. Over the past few years, this has led to an extensive research in the analysis of the flow characteristics in many different scenarios, [1], [3] or [4]. Once the flow structures are pictured, it is possible to propose a geometric modification that can improve the aerodynamic performance of trains. Dealing with these optimization problems has traditionally been done by a trial-and-error procedure, which is very expensive in terms of computer and designer time. Furthermore, this procedure strongly depends on the expertise of the engineer. Advanced optimization algorithms try to use the information extracted from these previous analyses while, at the same time, present a new strategy to solve the problem based in a more automated fashion. The application of these methods is very popular in aircraft or vehicle aerodynamics, but is still in progress in train aerodynamics,[4], [5] and [6]. Therefore, the interest of aerodynamic shape optimization for high-speed trains and the development and application of advanced optimization methods for train aerodynamics is evident. Here we propose the use of genetic algorithms (GA) for the aerodynamic optimization of the nose shape of a high-speed train subjected to cross-wind.

GA, [2], is a technique that mimics the mechanics of the natural evolution. Once a population of potential (optimal) solutions is defined, it combines survival-of-the-fittest concept to eliminate unfit characteristics and, after several iterations (generations), better results are obtained until a solution closer to the globally optimal solution is reached. The main drawback when using a GA is their need of a large number of evaluations of the objective function. Furthermore, each optimal candidate needs to be defined as

a codified structure, and since a set of individuals is required at each generation, an efficient representation of each possible optimal design (i.e. a high-speed nose shape) is demanded. Nose shrinking, bluntness and A-pillar roundness features are captured within the proposed parameterization. To overcome the requirement of a very large number of evaluations of the objective function, surrogate models are used. The surrogate-based optimization proposed here considers radial basis functions (RBF) to construct the surrogate model that will approximate the numerical solver, enabling a faster evaluation and optimization process.

The metamodel is used not only to help the GA to find the optimal design, but also to analyze the whole design space and determine the sensitivity of the objective function to the design variables. In this way, we can identify which are the most relevant design variables and quantify the effect of these on the objective function. [4] points out that the optimization of the aerodynamic performance of a train results into a multi-objective optimization problem since several aerodynamic objectives are known to be in conflict. Indeed, well rounded fronts of trains, which are beneficial for drag reduction, can deteriorate lateral stability. Therefore, it is expected that the importance of the design variables will change for different yaw angles or cross-wind scenarios, and so the optimal design. Our paper aims to solve the aerodynamic optimization of a high-speed train for four different yaw-angles and the multi-objective problem of the aerodynamic optimization of a high-speed train when considering two conflicting yaw-angles. Furthermore, the multi-objective optimization of minimizing the aerodynamic drag and side force is performed. In this case, a Pareto front of optimal solutions is obtained. Finally, conclusions about the influence of the considered design variables on the drag and side force are achieved.

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