Mass minimization of vehicle structure subject to varying crashworthiness constraints: a prediction–correction approach

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Abstract

This paper describes a methodology for minimizing the mass of a vehicle subject to crashworthiness constraints. It is implemented in the RADIOSS optimization tool M-OPT, and has proven to be very efficient in the framework of a study case for PSA Peugeot–Citroën.

Keywords: Optimization; Design of experiments; Kriging; Crashworthiness; Vehicle structure

1. Introduction

A large part of current vehicle structure is designed with regard to its crashworthiness. In this context, simulation programs such as RADIOSS [1] are used, and lead to improved vehicle architecture and sizing. In this paper, an optimization method based on response surfaces is presented. It is very efficient and makes crashworthiness optimization of practical and industrial interest. First, the theory is introduced and the M-OPT optimization toolbox [2] is described. Then, a study case for PSA Peugeot–Citroën is presented.

2. Presentation of the method

The present methodology consists of a sequence of approximation-based optimizations. It is very efficient and flexible.

2.1. Design of experiments and first approximation of the criteria

The first step is to produce a database of control points and to build approximations of the crashworthiness constraints as functions of the design variables. An exploratory optimal Latin hypercube (OLH) [3] design of experiments and a non-linear Kriging-type interpolation model [4] are used. Examples of OLH and Kriging interpolation can be seen in Fig. 1.

2.2. Prediction–correction iterations

The following sequence is then repeated until convergence (see Fig. 2):

1. *Prediction:* approached solutions are obtained by solving optimization problems using evaluations of the approximations only (no finite elements computation).
2. *Correction:* RADIOSS computations are then performed for each predicted solution and added to the database of control points; the approximations are then updated.

In step 1, the NLPQL algorithm [5] is used. Since it is a local optimizer, it gives results that depend on the chosen starting point. Several must therefore be used in order to obtain a global minimum, which means that several predictions–corrections are done at each iteration. Using this approach, 'interesting' design points are collected only at the neighbourhood of local minima, thus eliminating the useless construction of global response surfaces. The key to the convergence lies in its similarities with robust but simple methods such as the downhill simplex or 'golden search' method where no gradient information is required.

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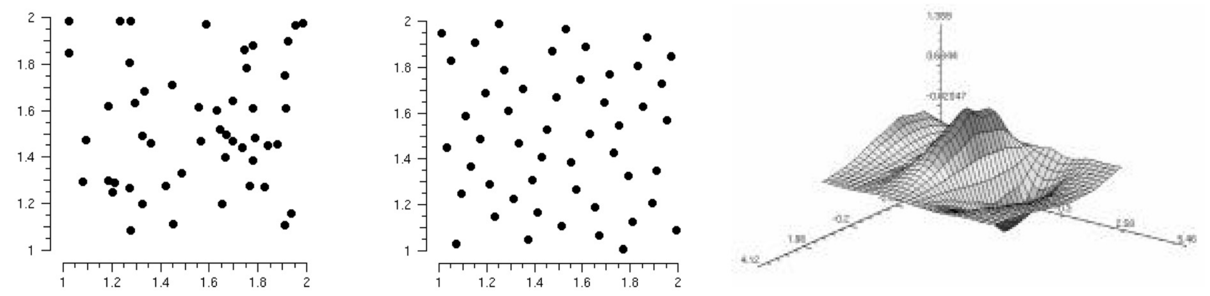


Fig. 1. Fifty samples distributed in 2D using Monte Carlo (a) and OLH (b), and an example of a Kriging-type response surface (c).

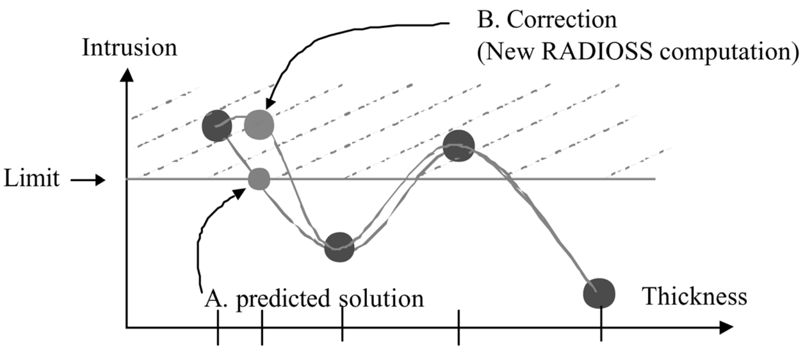


Fig. 2. Graphical explanation of the prediction–correction procedure.

2.3. Solving several problems corresponding to different values of the constraint limits

The only step in which the constraint limits are used is the prediction one. This is a very fast procedure, so several predictions corresponding to different problems can be obtained without any impact on the total cost of the study. The prediction step results in several approximated solutions, which can all be corrected in parallel with RADIOSS computations.

2.4. Convergence

Typically, 10 to 15 iterations are necessary. At the beginning, the predictions tend to underestimate the criteria and each set of RADIOSS computations gives important corrections to the response surfaces, then the prediction becomes increasingly improved. The convergence to a global minimum is guaranteed by the good coverage of the design space with the OLH, and by the use of several starting points in the prediction step for each iteration.

2.5. M-OPT optimization toolbox

This methodology is implemented in the optimization toolbox M-OPT [2]. It combines the parameterization of RADIOSS models in the pre-processors M-Crash or Helioss, with the construction of response surfaces, and the prediction–correction steps in the parametric analysis tool DSS. Snapshots of the graphical user interface can be seen in Fig. 3.

3. Industrial study case: PSA Peugeot–Citroën

The goal of this study was to minimize the structure of a vehicle subject to side impact crashworthiness constraints. Sixteen design variables (thickness of parts) and 20 constraints (displacements, loads, etc.) were used. The initial design was not feasible with a maximum constraint violation of 5%.

3.1. Design of experiments

First, an OLH of 30 samples was performed and some user-defined configurations were also tested. Based on these first results, it was realized that the initial feasible

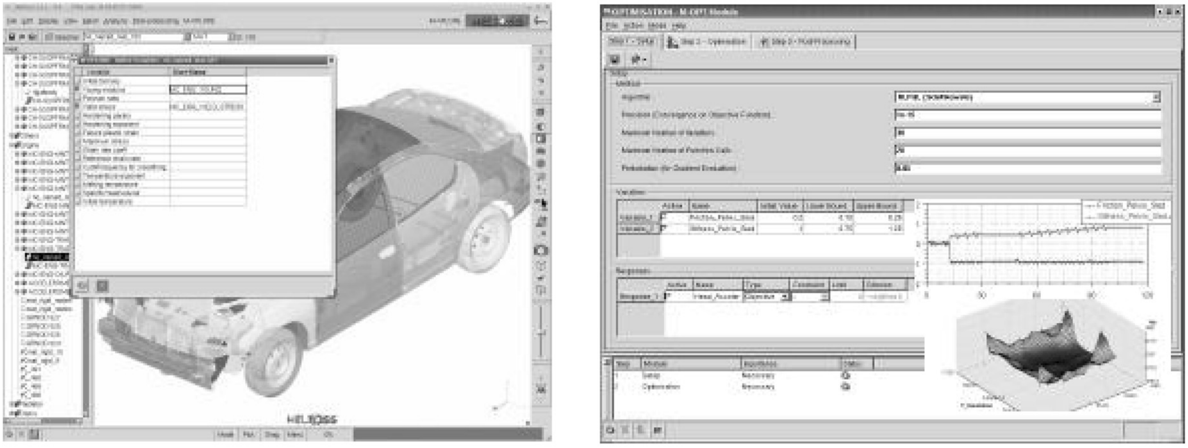
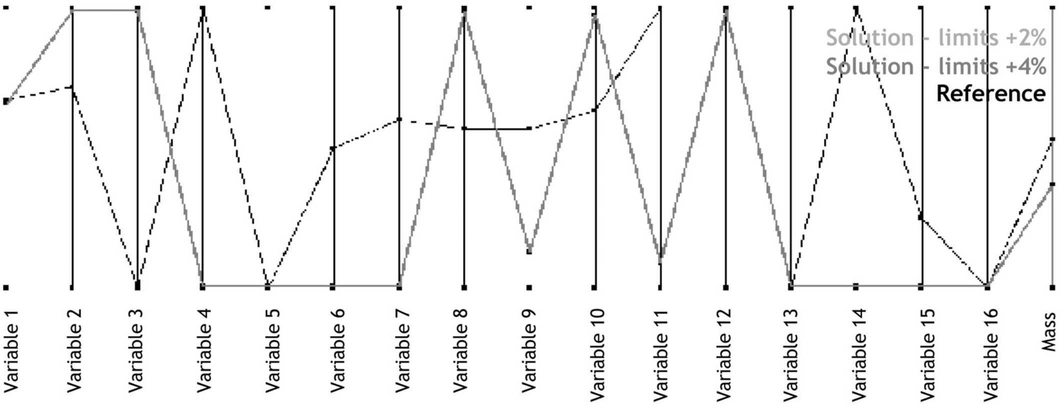


Fig. 3. The M-OPT user interface. (a) The RADIOSS pre-processor Helioss, (b) the parametric analysis toolbox DSS.



	Maximum constraint (limit = 100)	Mass
Initial design	105	100
Optimal Solution (constraint limits +2%)	102	98
Optimal Solution (constraint limits +4%)	104	94

Fig. 4. Results of the PSA Peugeot–Citroën study case.

solution was very hard to find: none of the samples were satisfying the constraints. It was therefore decided to authorize some violations of the constraint limits: two levels of violations were applied, +2% and +4%.

3.2. Optimization

Convergence was achieved after 40 computations. For 4% of violation of the constraint limits, i.e. almost as much as in the initial design, a mass reduction of 6% was obtained (see the results in Fig. 4). Only 4 out of the 20 constraints were violated in the obtained solutions, which shows that authorizing violations does not mean that all the violations will be used. Looking at the design variables, we could see that performing optimization does not simply consist in down gauging the parts: some thicknesses were increased and others decreased. The optimal design really corresponds to a new balance of the internal forces in the structure.

4. Conclusion

A mass minimization methodology has been presented. It has proven to be very efficient in the framework of an industrial study case. The fact that the method leads to a set of optimal designs for different values of the constraint limits is particularly interesting in an industrial context: it provides the project team with valuable information about the vehicle, and helps in choosing the best compromise.

References

[1] RADIOSS user's manual version 4.4, Mecalog, 2004.

[2] DSS/M-OPT user's manual version 2.2, Mecalog, 2004.

[3] Li W. Optimal designs using CP algorithms. In: Proc of the 2nd World Conference of the International Association for Statistical Computing, Pasadena, CA, 19–22 February 1997, pp. 130–139.

[4] Trochu F. A contouring program based on dual kriging interpolation. Eng Comput 1993;9:160–177.

[5] Schittkowski K. NLPQL, a Fortran subroutine for solving constrained nonlinear programming problems. Ann Operations Res 1985/1986;5:485–500.