Parametric CAD model based shape optimization using adjoint functions

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Abstract

Adjoint methods have proven to be an efficient way of calculating the gradient of an objective function with respect to a shape parameter for optimisation, with a computational cost nearly independent of the number of the design variables [1]. The approach in this paper links the adjoint surface sensitivities (gradient of objective function with respect to the surface movement) with the parametric design velocities (movement of the surface due to a CAD parameter perturbation) in order to compute the gradient of the objective function with respect to CAD variables.

For a successful implementation of shape optimization strategies in practical industrial cases, the choice of design variables or parameterisation scheme used for the model to be optimized plays a vital role. Where the goal is to base the optimization on a CAD model the choices are to use a NURBS geometry generated from CAD modelling software, where the position of the NURBS control points are the optimisation variables [2] or to use the feature based CAD model with all of the construction history to preserve the design intent [3]. The main advantage of using the feature based model is that the optimized model produced can be directly used for the downstream applications including manufacturing and process planning.

This paper presents an approach for optimization based on the feature based CAD model, which uses CAD parameters defining the features in the model geometry as the design variables. In order to capture the CAD surface movement with respect to the change in design variable, the "Parametric Design Velocity" is calculated, which is defined as the movement of the CAD model boundary in the normal direction due to a change in the parameter value.

The approach presented here for calculating the design velocities represents an advancement in terms of capability and robustness of that described by Robinson et al. [3]. The process can be easily integrated to most industrial optimisation workflows and is immune to the topology and labelling issues highlighted by other CAD based optimisation processes. It considers every continuous ("real value") parameter type as an optimisation variable, and it can be adapted to work with any CAD modelling software, as long as it has an API which provides access to the values of the parameters which control the model shape and allows the model geometry to be exported. To calculate the movement of the boundary the methodology employs finite differences on the shape of the 3D CAD models before and after the parameter perturbation. The implementation procedure includes calculating the geometrical movement along a normal direction between two discrete representations of the original and perturbed geometry respectively. Parametric design velocities can then be directly linked with adjoint surface sensitivities to extract the gradients to use in a gradient-based optimization algorithm.

The optimisation of a flow optimisation problem is presented, in which the power dissipation of the flow in an automotive air duct is to be reduced by changing the parameters of the CAD geometry created in CATIA V5, Fig. 1a. The flow sensitivities are computed with the continuous adjoint method for a laminar and turbulent flow [4] and are combined with the parametric design velocities (Fig. 1b) to compute the cost function gradients. A line-search algorithm is then used to update the design variables and proceed further with optimisation process.

Keywords: CAD, design velocity, shape optimization, continuous adjoint

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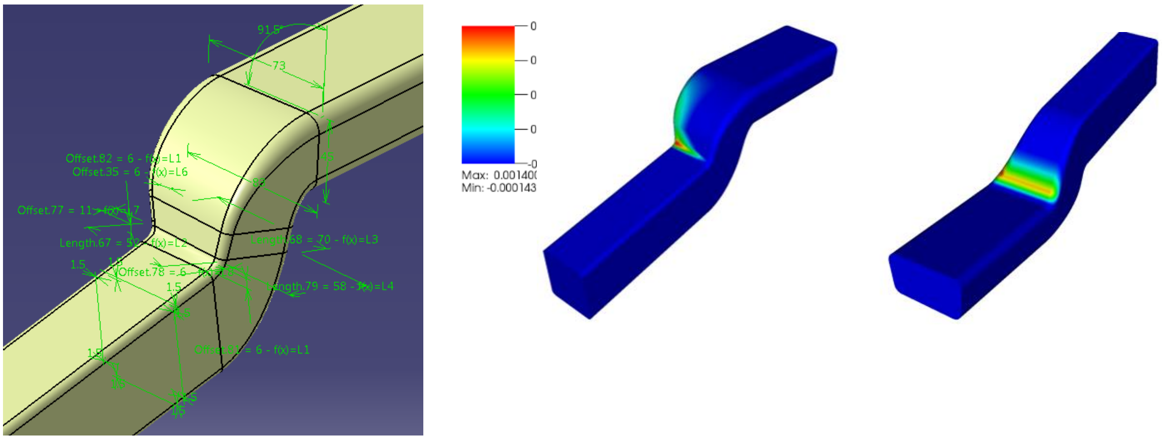
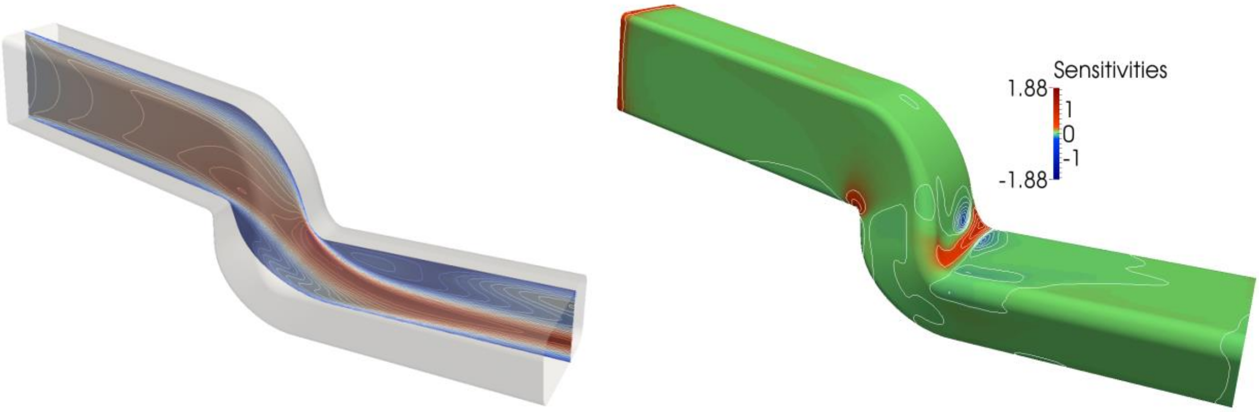


(a) (b)

Fig 1. (a) Automotive air duct Model in CATIA V5 (b) Parametric design velocity field



(a) (b)

Fig 2. (a) Automotive air duct geometry and velocity profile (b) Surface sensitivities calculated with the continuous adjoint method. To reduce power dissipation, areas with positive values (red) have to be pulled out and areas with negative values (blue) to be pushed inwards

Preliminary Results

Optimization results with initial developments (using steepest descent) have shown good results resulting in a reduction of objective function (power dissipation) by nearly 4 % for laminar flow simulations. Further reduction is expected on using a suitable line-search algorithm in the optimization framework.

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