# A comparison of node-based and CAD-based automatic parametrisations in shape optimisation

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**We present two automatic parametrisations that can be derived directly from either the CFD mesh or the generic CAD STEP representations. Shape optimisation is performed with both approaches coupled to a discrete adjoint solver and results are compared.**

## I. Introduction

Aerodynamic shape optimisation with gradient-based methods is rapidly gaining popularity in the aerospace and automotive industries. The most effective method to compute the required sensitivities is the adjoint method which allows to compute sensitivities of an arbitrary number of design variables at constant computational cost. This in turn opens up a wide range of possibilities to parametrise the shape as the number of design variables is no longer a limiting factor as long as the parametrisation algorithm can also differentiated in reverse mode.

A wide range of parametrisations have been proposed for aerodynamic shape optimisation.[1] Of particular interest to us are parametrisations that do not require manual setup but can be derived automatically from existing information. One the one hand we will consider a node-based parametrisation which uses the surface nodes of the CFD grid as design variables. On the other hand we will consider CAD-based parametrisations based on the boundary representation (BRep) as given in the STEP file format.

## II. Automatic shape parametrisations

Most shape parametrisation methods require manual setup. Setting up auxiliary grids for lattice-based methods, such as e.g. auxiliary grids with Hicks-Henne bumps on aerofoils or stacked spline curves for turbomachinery blades, involve substantial effort and are difficult to extend to complex geometries. Free-form deformations such as volume splines require the definition of auxiliary hexahedral volume grids that need to be snapped to the geometry to preserve features.

Adjoint methods do not penalise the size of the design space, hence we can consider very large spaces that guarantee to incorporate the largest possible number of degrees of freedom. With limitations on the design space being alleviated we can consider fully automatic parametrisations that do not require any manual definition by the user but can be derived from existing data.

In the node-based parametrisation, displacements of the surface grid nodes are the design variables which offers the richest design space the CFD discretisation can consider. As a matter of fact, this design space is even too rich for the CFD as the parametrisation method can express high-frequency modes which are not adequately resolved by the CFD and hence remain poorly damped. Additional regularisation is necessary, and implicit[2] as well as explicit[3] smoothing methods have been proposed, both of them requiring to tune a smoothing coefficient. The disadvantage of the method is that the optimal shape exists only as a mesh, transcription to CAD is not straightforward and any approximation will incur a loss of optimality.

As an alternative, the CAD based approach NSPCC[4,5] works with the CAD geometry in the optimisation loop and produces the optimal shape in CAD. NSPCC considers movements of the control points of the NURBS patches of the BRep to alter the shape. The resulting design space is hence the richest space the provided BRep can express.

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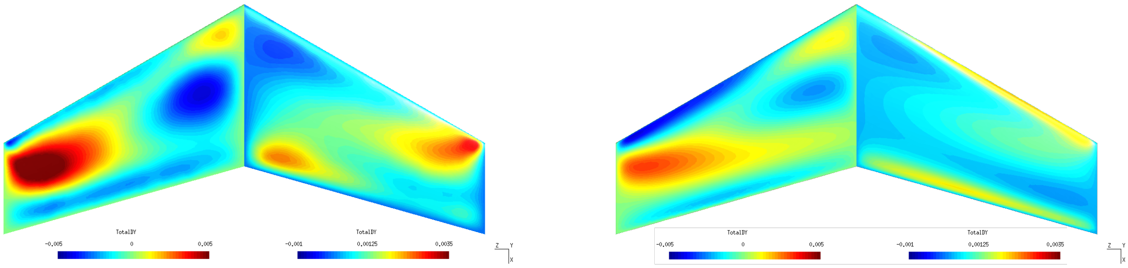
To enforce continuity between patches such as G1 (tangency) or G2 (curvature), constraint equations are numerically evaluated at testpoints distributed along the patch interfaces. The Jacobian of the constraint equations is assembled and the design space is the kernel of this Jacobian which is evaluated using a Singular Value Decomposition. The design variables then effectively become the vectors associated with non-singular values. Again there is an adjustable parameter in the form of the threshold value for singular values.

## III. Results

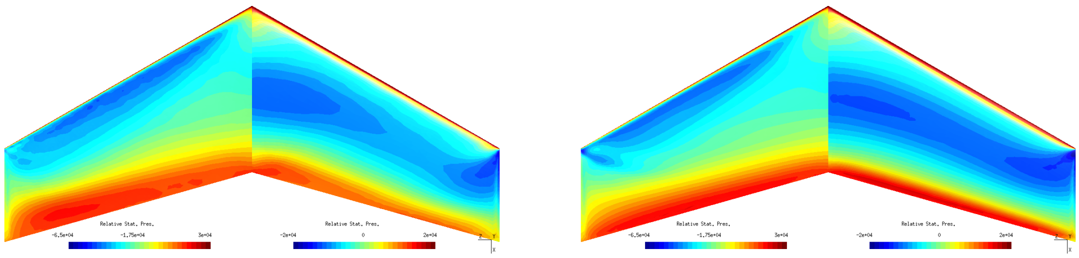
In this paper performance, efficiency and capabilities of the both CAD and node-based methods are discussed and compared on a U-Bend testcase using an in-house flow and adjoint solver for the compressible Navier-Stokes equations.

Comparison of the two approaches for the inviscid transonic flow over an Onera M6 wing are shown in Figs. 1 and 2. The objective is to minimise drag subject to constant lift. The node-based method uses the displacement of 26,000 surface nodes regularised with 20 sweeps of explicit smoothing,[3] The CAD-based method uses two patches joining at leading and trailing edge with $13\times12$ points each, in total $2\times468$ DoF.



(a) *Node-based* (b) *CAD-based*

Figure 1: Drag minimisation of M6 wing, shape displacements for node-based (left) and CAD-based parametrisation (right).



(a) *Node-based* (b) *CAD-based*

Figure 2: Drag minimisation of M6 aerofoil, pressure for node-based (left) and CAD-based parametrisation (right).

Although the design spaces have vastly different sizes, the comparison for the top surface shows that very similar displacement modes are found by both parametrisation methods. The displacements of the lower surface exhibit differences, but the flowfield demonstrates that the objective function in both cases is very similar, it has low sensitivity against the bottom shape and is most likely multi-modal.

The presentation will expand the comparison to duct cases.

## References


[1]Samareh, J., "Survey of Shape Parameterization Techniques for High-Fidelity Multidisciplinary Shape Optimization," *AIAA Journal*, Vol. 39, No. 5, 2001, pp. 877–884.

[2]Jameson, A. and Vassberg, A., "Studies of alternative numerical optimization methods applied to the brachistochrone problem," *Computational Fluid Dynamics Journal*, Vol. 9, No. 3, 2000.

[3]Jaworski, A. and Müller, J.-D., "Toward modular multigrid design optimisation," *Lecture Notes in Computational Science and Engineering*, edited by C. Bischof and J. Utke, Vol. 64, Springer, "New York, NY, USA", 2008, pp. 281–291.

[4]Xu, S., Jahn, W., and Müller, J.-D., "CAD-based shape optimisation with CFD using a discrete adjoint," *International Journal for Numerical Methods in Fluids*, Vol. 74, No. 3, 2013, pp. 153–68.

[5]Xu, S., Radford, D., Meyer, M., and Müller, J.-D., "CAD-based adjoint shape optimisation of a one-stage turbine with geometric constraints," ASME Turbo Expo 2015, June 2015, GT2015-42237.