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Discrete adjoint solvers for industrial design optimisation

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Adjoint solvers can compute sensitivity information for large numbers of input variables at very low computational cost and have hence become essential ingredients in design optimisation for fluid flow. Their potential and capability has been demonstrated with seminal works in the aeronautical industry, the FlowHead project aims to progress with adjoint-based optimisation in the automotive industry. The work presented here will focus on two aspects where general industrial application differs from application in aeronautics: a) suitable general flow solvers, and b) automated general design parametrisations.

In the automotive industry maintaining their own numerical analysis tools such as flow solvers is typically not practised, instead one relies on commercially licensed and supported software. Hence the adjoint solvers suitable for general application need to be compatible with these solvers, using the typical pressure-based discretisations and be robust in their accuracy and stability. The discrete adjoint approach is generally considered the more robust approach as the discrete approach transfers the linear stabilty of the primal CFD solver, which is well understood, to the adjoint.

In this presentation we demonstrate application of Automatic Differentiation (AD) to a generic pressure-based flow solver to derive an incompressible adjoint. The ability of the leading Fortran AD tool to cope with modern Fortran90 language constructs such as modules and derived data types is discussed, as well as how to handle external library calls. Tangent linear and adjoint results are shown and the performance is evaluated. This methodology is then applied to a large commercial flow solver (CFD ACE+) and the results are presented.

In aeronautics and turbomachinery the standard optimisation cases of wing profiles and planforms are sufficiently generic that bespoke parametrisaton chains can be set up. This is not the case in general engineering application. Node-based and morphing-based parametrisations are popular and can be set up with no or limited user effort, however the optmial design does not exist in CAD form for further analysis and relevant design modes need to be extracted by hand. Including the CAD system in the design loop can currently only be done using finite differences, which is computationally inefficient and can have problems with robustness.

We present an alternative that uses the control of the NURBS boundary representation (BRep) as design variables. We formulate linear constraints that impose geometric continuity of 0th, 1st or 2nd Order at patch interfaces and derive an orthonormal set of permissible shape modes. The optimal design then exists as a BRep and can be fed back into the virtual prototyping chain. Results on application to automotive testcases will be presented.