

# An Adjoint Solver for an Industrial CFD Code via Automatic Differentiation

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## 1 Introduction

Industrial use of CFD is now routine and the current challenge is to incorporate large scale CFD codes into the engineering design cycle via design optimisation. The associated use of gradients is non-trivial and is the subject of the monograph [6]. Aerodynamic designs may have 100's of design variables making adjoint methods, which compute gradients in time proportional to the (small) number of design objectives [4], attractive. Here we concentrate on discrete adjoint methods, in which the discretised flow solver is adjointed, since it may be generated and maintained by automatic differentiation (AD) [5] tools. Previously [7] we described using the Odyssey AD tool [3] to obtain and validate a discrete forward sensitivity version of the BAE SYSTEMS/AIRBUS UK unstructured mesh CFD code FLITE3D. In this paper we report on the generation, validation and performance optimisation of the corresponding adjoint solver.

## 2 The Flite3D CFD Package

Neglecting RK time-stepping and multigrid, FLITE3D's solver is described by (1–4).

$$\left. \begin{array}{l} \text{Surface Mesh Generator} \\ \text{Given design parameters } \underline{\beta} \\ \text{Surface mesh generation } \mathbf{x}_S = \mathbf{X}_S(\underline{\beta}) \end{array} \right\} \quad (1)$$

$$\left. \begin{array}{l} \text{Volume Mesh Generator} \\ \text{Volume Mesh generation } \mathbf{x} = \mathbf{X}(\mathbf{x}_S) \end{array} \right\} \quad (2)$$

$$\left. \begin{array}{l} \text{Geometric Pre-Processor} \\ \text{Calculate point and face surface normals } \mathbf{n}(\mathbf{x}_S, \underline{\beta}), \mathbf{n}(\mathbf{x}_S) \\ \text{Calculate Volume Mesh normals } \mathbf{w}(\mathbf{x}, \mathbf{x}_S) \end{array} \right\} \quad (3)$$

$$\left. \begin{array}{l} \text{Flow Solver} \\ \text{Initialise flow variables } \mathbf{u}^0 \\ \text{Do } \quad \mathbf{n} = 0, n_{\max} - 1 \\ \quad \text{Finite volume residual } \mathbf{r}^n = \mathbf{R}(\mathbf{u}^n, \mathbf{x}, \mathbf{w}, \mathbf{n}) \\ \quad \text{If (converged) Exit Do Loop} \\ \quad \mathbf{u}^{n+1} = \mathbf{u}^n - \mathbf{P}_L(\mathbf{u}^n, \mathbf{x})\mathbf{r}^n \\ \quad \text{Aerodynamic Coefficients } [C_L, C_D, M_y] = C(\mathbf{u}^n, \mathbf{x}, \mathbf{n}) \\ \text{EndDo} \end{array} \right\} \quad (4)$$

Given design parameters  $\underline{\beta}$ , for example B-spline coefficients, a surface mesh  $\mathbf{x}_S(\underline{\beta})$  is generated, followed by the volume mesh  $\mathbf{x}$  using Delaunay techniques. A geometric pre-processor then calcu-

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