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FIRST AND SECOND ORDER SENSITIVITY EQUATION METHOD FOR VALUE AND SHAPE PARAMETERS

A. Hay^a and F. Ilinca^b and D. Pelletier^a

^aDépartement de génie mécanique
Ecole Polytechnique de Montréal
Montréal, Québec, Canada
alexander.Hay@Polymtl.ca, Dominique.Pelletier@Polymtl.ca

^bIndustrial Materials Institute
National research Council of Canada
75, boul. de Mortagne
Boucherville, Québec, Canada
Florin.Ilinca@nrc.ca

We present formulations of the Sensitivity Equation Method (SEM) for analysis of a broad class of flow problems ranging from steady laminar flow, through steady state turbulent flows modeled by the RANS equations to unsteady laminar flows.

Flow sensitivities are essentially the derivatives of dependent flow variables (velocity, pressure, temperature) with respect to parameters of interest. These fall in two categories. **Value** parameters do not affect the geometry of the computational domain and lend themselves to a simple numerical treatment; for example an inflow velocity or a coefficient in a constitutive equation. **shape** parameters are more challenging because a variation of their values causes changes to the geometry of the computational domain; examples include coefficients in a Bezier curve, or coordinates and weights of control points in a NURBS.

In design optimisation, adjoint formulations are often the preferred route because only one adjoint problem need be solved independently of the number of design variables. Whereas one sensitivity system must be solved for each design parameter. However, sensitivities offer interesting possibilities. They may be advantageous when several functionals must be optimized simultaneously. For unsteady flows Sensitivity equations are integrated forward in time with the flow equations whereas the adjoint system must be integrated backwards in time with the flow solution acting as data. For time-dependent flows, sensitivities appear to be able to foretell changes in the flow structure long before they can be detected by looking at the flow time signals thus offering excellent possibilities in flow optimisation.

Sensitivities are a very cost effective tool to cascade input data uncertainties through the CFD code to obtain estimates of the uncertainty of the flow response. This could be used in the context of design with uncertainty. They are a very efficient approach for fast evaluation of flows at nearby values of the parameters. Because sensitivities can be obtained at a fraction of the cost of a flow solve, efficiency is achieved by using sensitivities in a Taylor series expansion in parameter space around a baseline solution.

The presentation will discuss issues, challenges with the various uses of the SEM. Techniques for dealing with these obstacles will be described; applications to analysis and/or optimisation of steady and time-dependent flows will be presented.