Automatic adjoint formulation with customized objective functions in an industrial CFD framework

Yingchen Li* , Kilian Claramunt† and Charles Hirsch‡
Numeca Int., Brussels, 1170, Belgium

The formulation of continuous adjoint method depends on the objective function. The present paper develops a flexible new way to customize the objective function within the frame of the industrial CFD code FINE/Open with OpenLabs™. The formulation of the adjoint equations, boundary conditions and sensitivity gradients is automatically derived by the system without user intervention. Several examples are presented to show the capability of interpreting various objective functions in a variety of applications.

I. Abstract

ADJOINT methods receive growing attention in aerodynamic shape optimization and mesh adaptation, due to its reduced computational cost in obtaining sensitivity gradient in a N-dimensional parameter space. However, the highly intrusive adjoint formulation depends on the objective function, making most of the adjoint solvers either limited to a list of predefined objective functions or requiring a dedicated re-programming to adapt to a new objective function.

The present paper develops a flexible new way to customize the objective function within the frame of the industrial CFD code FINE/Open with OpenLabs™. The engineer can define his objective functions by a text file, and the adjoint system (equations, boundary conditions as well as sensitivity gradients) will be adapted automatically by OpenLabs. OpenLabs is a user friendly component of FINE/Open, allowing the user to develop its own physical models, boundary or initial conditions, add new transport equations, …, without explicit programming.

The methodology is based on the continuous adjoint method. The general formulation of the adjoint system is firstly derived for the given prototype of the objective function, which involves both surface and volume integrals of flow quantities. Then, symbolic manipulations on the new objective functions are performed by OpenLabs, including integration by parts, Leibniz rule, differentiation using chain rule and algebraic manipulations. Both analytical and numerical differentiations, based on complex variable methods, are applied. Through the symbolic manipulations, the contributions of the objective functions to the adjoint system are formulated by OpenLabs, including 1) adjoint boundary condition; 2) source terms of adjoint equation (if any); 3) sensitivity gradients with respect to boundary conditions and to the surface mesh nodes. A shared library is then automatically created and plugged into the adjoint solver of FINE/Open with OpenLabs™. All steps above are performed fully automatically, without user intervention.

The objective functions can be defined as integrals over boundaries or domains, whose integrand can be defined as the algebraic combination of the flow variables and their 1st and 2nd-order spatial derivatives. In addition, the objective function can also be defined as linear, product or ratio combination of the integrals.

Several examples are presented in the paper to show the capability of FINE/Open with OpenLabs™ of interpreting various objective functions:

1. Validation: pressure inverse design.
2. Single objective: minimize entropy.
3. Multi objective: minimize mass flow averaged entropy with exit flow angle constraints.
4. Multi objective: minimize total pressure losses and minimize exit whirl angle.
5. Multi objective: maximize average heat transfer coefficient and minimize mass flow averaged total pressure losses.

Communicating Author: charles.hirsch@numeca.be.
* Responsible for OpenLabs, Multiphysics CFD Group, Chaussée de la Hulpe, 187-189, 1170 Brussels, Belgium
† Head of Multiphysics CFD Group, Chaussée de la Hulpe, 187-189, 1170 Brussels, Belgium
‡ Professor, Founder and President, Chaussée de la Hulpe, 187-189, 1170 Brussels, Belgium

Acknowledgments

The work described in this paper has been made possible by the fruitful and stimulating collaboration with the Laboratory of Prof. Kyriacos Giannakoglou and his team at the National Technical University of Athens (NTUA).

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