Adjoint-based Optimization Techniques in SU2 with Applications to Industrial Flows

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More than 25 years after the landmark article by Prof. Antony Jameson on the topic,[1] adjoint-based design and grid adaptation techniques can be found in many CFD solvers and have been successfully demonstrated across a wide range of applications. Recent advances are improving the robustness and accuracy of these methods even for the complex geometries and unstructured grids needed within industrial environments. The objective of this presentation is to overview the adjoint-based methods available within the open-source SU2 software suite and how, along with native modules for geometry parameterization and mesh deformation, the methods can be applied to industry-scale design problems. Shape optimization results for the NASA Common Research Model (CRM) and Lockheed Martin 1021 (LM1021) aircraft geometries will be presented.

I. Introduction

SU2 is an open-source integrated analysis and design tool kit for solving complex, multi-disciplinary problems on unstructured computational grids.[2] At its core, the software suite is a collection of C++ modules, linked within a Python framework, that performs the discretization and solution of partial differential equation-based (PDE) problems and executes PDE-constrained optimization tasks. The object-oriented architecture of SU2 is easy to read, learn, and modify in order to treat unique problems across a wide range of engineering disciplines. These capabilities and the open-source philosophy position SU2 uniquely within the CFD community to become a test-bed for computational scientists interested in the high-fidelity analysis and design of complex engineering systems.

The objective of this presentation is to overview the adjoint-based methods available within the SU2 suite and how, along with native modules for geometry parameterization and mesh deformation, the methods can be applied to industry-scale shape design problems.

II. Adjoint Methods within SU2

Owing to the open-source community, the SU2 code contains two distinctly different implementations of the adjoint methodology that have been completed by experts in the field: a continuous adjoint by Stanford University and a discrete adjoint via algorithmic differentiation (AD) of the entire solver by the Technical University of Kaiserslautern.

SU2 features a native continuous adjoint solver in a surface formulation based on the frozen turbulent viscosity assumption.[3] Since debuting in the initial public release of SU2, the continuous adjoint solver has been extensively used and rigorously tested[4,5] for both inviscid and viscous problems across many flow regimes.

More recently, a discrete adjoint solver in SU2 has been generated by algorithmically differentiating the entire codebase. To be more precise, this includes not only the flux routines, but also the complete nonlinear iteration structure of the solver. To improve efficiency, the group at the Technical University of Kaiserslautern has developed a custom set of AD tools specifically tuned for CFD applications. Currently, the discrete adjoint solver has been implemented for the Euler, Navier-Stokes, and RANS equations (S-A and SST turbulence models) in combination with all of the existing design parameterizations available in SU2.[6,7]

Modules for performing flow and adjoint solutions, acquiring gradient information by projecting sensitivities into the design space, and mesh deformation techniques are all included in the suite, amongst others. Typically, geometry parameterization is accomplished with a free-form deformation approach,

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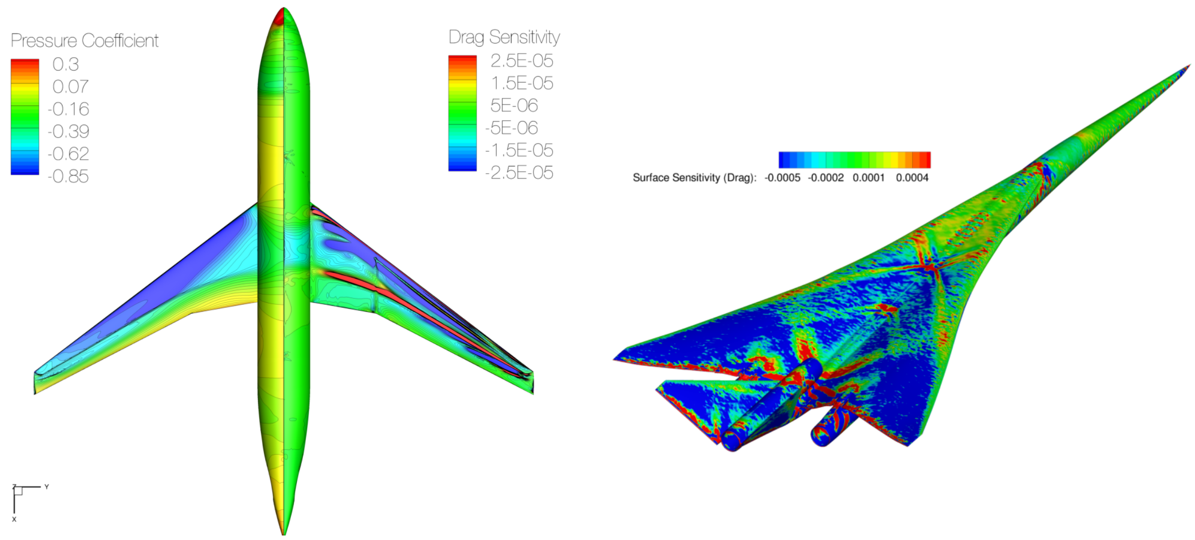
mesh deformation with an elasticity-based approach, and the shape design loop is driven by the SLSQP optimizer found in the SciPy library.[8]



(a) Pressure coefficient (left) and surface sensitivity (right) contours on the upper surface of the CRM configuration.

(b) Drag sensitivity contours on the LM1021 configuration as computed by SU2.

Figure 1. Two applications of optimal shape design to industrial flow problems with SU2.

III. Shape Design Applications

After demonstrating some ideas on simple test cases, two examples of applying SU2 to shape design of industry-scale problems will be presented: the NASA Common Research Model (CRM) and Lockheed Martin 1021 aircraft geometries, as shown in Fig. 1.

The NASA CRM has been selected as a baseline model for further investigation. It was developed to be used in CFD validation exercises as part of the fourth AIAA CFD Drag Prediction Workshop.[9] This wing-body-tail configuration provides a challenging problem due to its geometric complexity and the large, unstructured meshes employed during its analysis. In terms of the proposed design problem, the objective will be to minimize drag while imposing lift and moment constraints. Geometrical constraints will be included to guarantee the feasibility of the final design.

In recent years, there has been renewed interest in low-boom supersonic aircraft. Advances in simulation-based design, including adjoint methods, are opening the door to new supersonic aircraft designs with reduced sonic boom impacts. The Lockheed Martin 1021 (LM1021) is one of the test cases from the AIAA 1st Sonic Boom Prediction Workshop,[10] and it will be used to demonstrate adjoint-based optimization of a supersonic configuration.

References

[1] A. Jameson. Aerodynamic design via control theory. *Journal of Scientific Computing*, 3(3):233–260, 1988.

[2] T. D. Economon, F. Palacios, S. R. Copeland, T. W. Lukaczyk, and J. J. Alonso. SU2: An open-source suite for multiphysics simulation and design. *AIAA Journal*, 54(3):828–846, 2015.

[3] C. Castro, C. Lozano, F. Palacios, and E. Zuazua. A systematic continuous adjoint approach to viscous aerodynamic design on unstructured grids. *AIAA Journal*, 45(9):2125–2139, 2007. DOI: 10.2514/1.24859.

[4] F. Palacios, T. D. Economon, and J. J. Alonso. Large-scale aircraft design using SU2. AIAA Paper 2015-1946, January 2015.

[5] T. D. Economon, F. Palacios, and J. J. Alonso. Unsteady continuous adjoint approach for aerodynamic design on dynamic meshes. *AIAA Journal*, 53(9):2437–2453, 2015.

[6] T. Albring, M. Sagebaum, and N.R. Gauger. Development of a consistent discrete adjoint solver in an evolving aerodynamic design framework. AIAA Paper 2015-3240, 2015.

[7] B.Y. Zhou, T. Albring, N.R. Gauger, T. D. Economon, F. Palacios, and J. J. Alonso. A discrete adjoint framework for unsteady aerodynamic and aeroacoustic optimizatio. AIAA Paper 2015-3355, 2015.

[8] E. Jones, T. Oliphant, P. Peterson, et al. SciPy: Open source scientific tools for Python, 2001.

[9] J. C. Vassberg, M. A. DeHaan, S. M. Rivers, and R. A. Wahls. Development of a common research model for applied CFD validation studies. AIAA Paper 2008-6919, 2008.

[10] J. M. Morgenstern, M. Buonanno, and F. Marconi. Full configuration low boom model and grids for 2014 sonic boom prediction workshop. Number AIAA Paper 2013-647, 2013.