SHAPE SENSITIVITY OF WING BOX PANELS IN AN AUTOMATED STRUCTURAL OPTIMIZATION SYSTEM (ASTROS)

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ABSTRACT

Continuum sensitivity analysis (CSA) provides an efficient framework for analytically computing design derivatives of aeroelastic response with respect to shape parameters that control the aircraft outer mold line. CSA offers significant advantages over the finite difference and discrete analytical methods of sensitivity analysis in terms of accuracy and computational cost. Despite its potential advantages, the boundary velocity approach to CSA has seen limited adoption due to the challenge of obtaining accurate spatial derivatives needed for its sensitivity loads in the presence of structural interfaces.

This work presents the development and demonstration of an enhanced CSA capability within the NASTRAN-compatible Automated Structural Optimization System (ASTROS) program [1]. While ASTROS has been a a widely used tool for aeroelastic analysis for more than three decades in the Air Force Research Lab and industry, its existing sensitivity infrastructure supports design derivatives only for sizing optimization, but not shape optimization. Enhancing ASTROS' sensitivity analysis capabilities is therefore of broad practical value. In this study, a novel modification to the ASTROS sensitivity framework is introduced, which enables accurate evaluation of shape derivatives, accounting for structural interfaces, extending its applicability to a wider class of engineering problems. The grand challenge problem for our current research is the calculation of shape sensitivities for the X-15 hypersonic vehicle (Figure 1), which serves as a motivating application throughout this work [2].

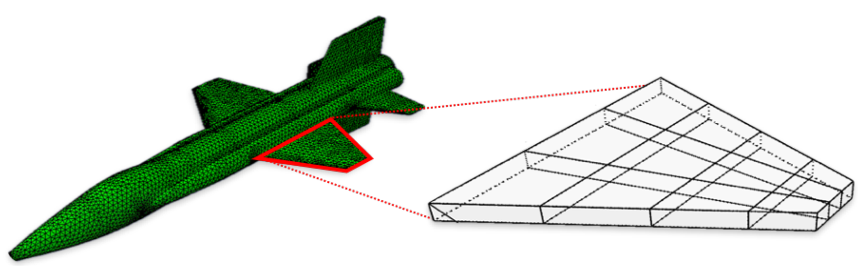

Figure 1: Wing Panel Benchmark Problem

Preliminary results for an academic benchmark problem of a rectangular plate subject to a sinusoidal pressure load have verified the accuracy of the spatial gradient reconstruction (SGR) relative to an exact analytical solution and as drastically more accurate than semi-analytic discrete

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sensitivity analysis in NASTRAN and more accurate than finite difference on a fine mesh (Figure 2). To assess the accuracy and performance of the enhanced CSA implementation in the

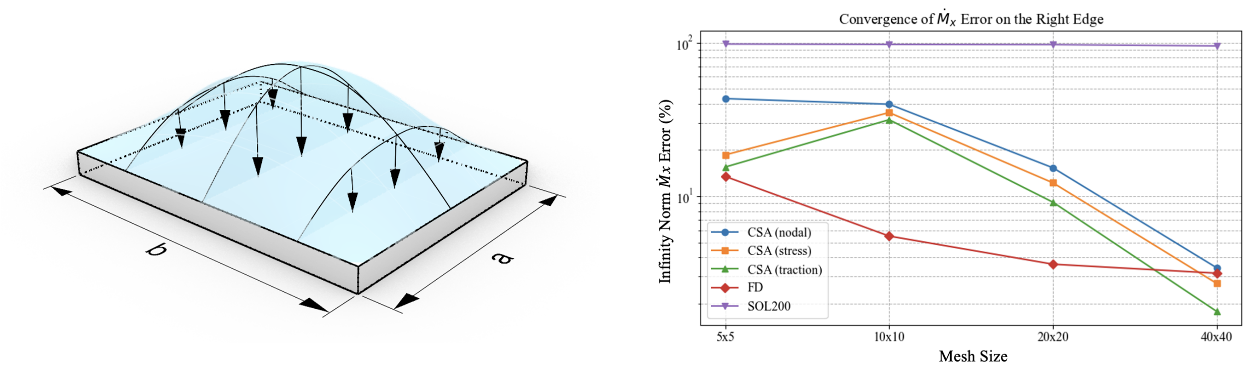

Figure 2: Convergence of Shape Derivative of Bending Moment with Respect to Width, a, of a Plate Subject to Sinusoidal Pressure Load

presence of structural interfaces, first, results for a simple stiffened plate will be presented in our IFASD presentation (Figure 3). This benchmark problem provides a representative test case for demonstrating the methodology and evaluating numerical accuracy. We expect that CSA results will show strong agreement with the finite difference sensitivities when an optimal perturbation step size is selected. The methodology then will be extended to a more complex wing box model (Figure 1), representative of an X-15 wing, to demonstrate the capability to handle additional geometric and modeling complexity.

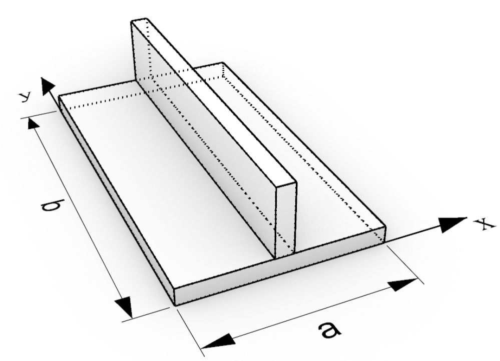

Figure 3: Stiffened Beam Benchmark Problem

The results of this study demonstrate that ASTROS, already a powerful analysis and optimization tool, can be significantly enhanced through incorporation of CSA for shape optimization. By enabling accurate and efficient shape sensitivity computation for problems involving structural interfaces, the proposed enhancements broaden the range of multidisciplinary design optimization problems that can be addressed with ASTROS. This work represents a step toward making CSA a practical tool for real-world aerothermoelastic design applications, supporting higher-fidelity optimization with reduced computational expense.

References

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