

Dan Berkenstock  
Aerospace Design Laboratory

## Abstract

Methods for modification of complex aerodynamic configurations suffer from several drawbacks in current shape optimization efforts. The use of parametric Computer Aided Design (CAD) software allows for global or local shape perturbation, but requires manual identification of all design variables. Bump functions allow for local shape perturbation, but lead to extremely large and noisy design spaces.

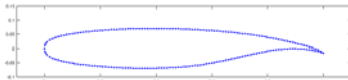
The purpose of this research is to pursue optimization of complex configurations through an automated, level-of-detail approach. Splines are used to approximate the structure of a given geometry using an arbitrary number of control points. The geometry is then redefined in relation to this underlying structure. Combining geometry definitions using an increasing number of control points allows shape optimization to be performed in a hierarchical manner.

## Method Overview

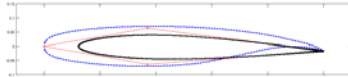
**Goal:** Parameterize & modify complex shape by redefining geometry in terms of reduced-order structure preserving spline approximation (SPSA).

**Step 1:** Import Complex Geometry

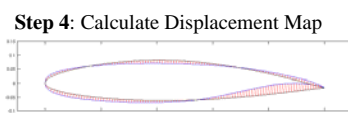
Ex: NASA SC(2)-0714 supercritical airfoil



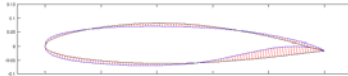
**Step 2:** Coarsen to SPSA<sup>1</sup> control net



**Step 3:** Fit SPSA<sup>1</sup> as quasi-interpolant

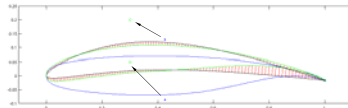


**Step 4:** Calculate Displacement Map



**Step 5:** Perturb SPSA<sup>1</sup> Control Points

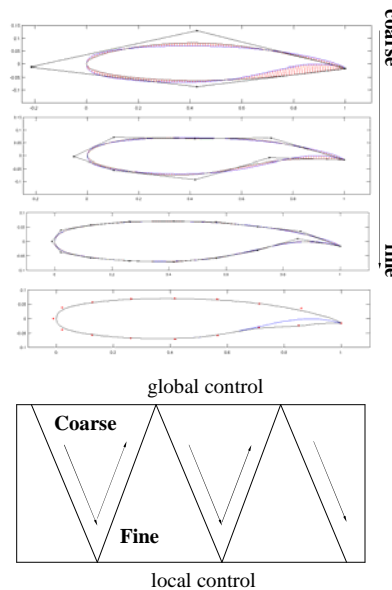
**Step 6:** Rebuild Geometry



## Hierarchical Optimization

**Global vs. Local Control:**

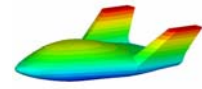
Knot insertion in SPSA<sup>1</sup> allows for shape control with arbitrary number of degrees of freedom. Note this is not a reduced order representation of the geometry, but allows for multiple modification modes.



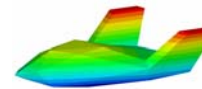
## 3 Dimensional Case

It is possible to extend this approach to three dimensions by using a class of splinar surfaces that offer efficient parameterization and representation of geometries of arbitrary topology.

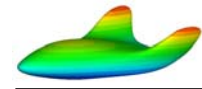
### Structural Modification



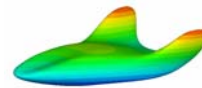
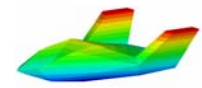
Complex geometry



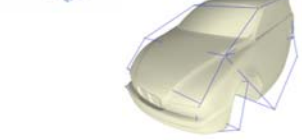
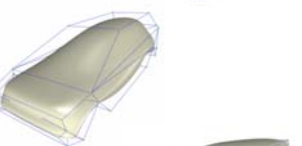
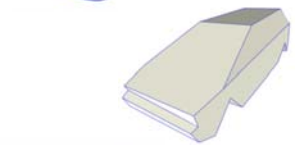
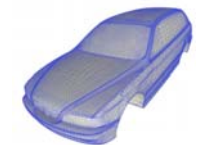
SPSA<sup>1</sup>



Modified SPSA<sup>1</sup>



### Complex Geometry Modification<sup>2</sup>



## Sample Problem

**Problem:** Maximize lift to drag ratio for given airfoil at low Mach number and zero angle of attack

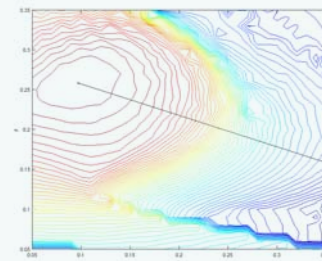
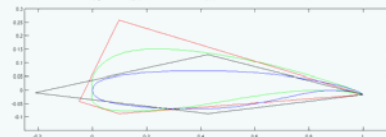
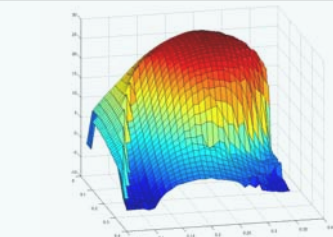
**Objective Function Evaluator:** XFOIL

**DV 1:** x location of top spline control point

**DV 2:** y location of top spline control point

**Optimizer:** SQP optimizer with finite difference gradient approximation

**Result:** ~4x increase of lift to drag ratio



## Future Work

Methods for hierarchical geometry modification are well established, however, these methods have not been widely employed in numerical shape optimization. Future work will primarily focus on analysis of convergence properties of this hierarchical approach to numerical shape optimization.

(1) Structure Preserving Spline Approximation (SPSA)

(2) M. Marinov & L. Kobbelt, Automatic Generation of Multiresolution Models, Eurographics 2005, Volume 24.

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