ANALYTICAL SENSITIVITY ANALYSIS OF GEOMETRICALLY NONLINEAR STRUCTURES UTILIZING THE CO-ROTATIONAL FINITE ELEMENT METHOD

Joseph M Pajot[a] and **Kurt Maute**[a]

[a]Department of Aerospace Engineering
The University of Colorado
Boulder, Colorado 80309-0429
joseph.pajot@colorado.edu
kurt.maute@colorado.edu

The computation of the gradients of a structural response with respect structural parameters is of crucial importance in a broad class of design optimization algorithms and stochastic analysis techniques. Finite differencing methods are often preferred, as they require only minor modifications of existing finite element analysis software. However, finite differencing methods are computationally costly and often become inaccurate, in particular if the nonlinear behavior of structures needs to be considered. Analytical methods overcome these shortcomings but require substantial code development, including the derivation of nonlinear element formulations with respect to structural parameters.

In order to limit the efforts associated with analytical sensitivity analysis methods, the co-rotational finite element method is revisited for computing structural sensitivities with respect to geometrical and material parameters for geometrically nonlinear structures. The co-rotational finite element method provides a procedure to formulate geometrically nonlinear elements based off an already pre-existing library of linear finite elements. This feature will be further exploited for analytical sensitivity analysis methods.
The benefits of the co-rotational method in sensitivity analysis are threefold:

- Robust linear elements may be used as the basis for the nonlinear element, which preserves the desirable performance attributes of the linear element while avoiding the formulation of completely nonlinear elements such as those from an updated or total Lagrangian formulation.
- Many of the element-dependent routines used for linear sensitivity analysis may be reused for the nonlinear analysis.
- The element independent framework of the co-rotational method allows for relative ease in the implementation of new element formulations including the derivations with respect to structural parameters.

The co-rotational formulation used in this study is the projector based method that was first introduced by Nour-Omid and Rankin [1]. The formulation of the sensitivity equation will be presented and the interface to linear element formulations discussed. The computational complexity of the proposed approach will be analyzed for the direct and adjoint sensitivity analysis formulation. Also, the accuracy of the geometrically nonlinear response and its sensitivities will be compared to fully nonlinear formulations. The potential of the co-rotational approach will be illustrated by the shape optimization of inflatable structures.

References

[1] B. Nour-Omid and C.C. Rankin, "Finite Rotation Analysis and Consistent Linearization Using Projectors," *Computer Methods in Applied Mechanics and Engineering*, v. 93, p. 353-384, 1991.