Developing Procedures to Implement Geometric Imperfections Beyond Right Circular Cylindrical Shells in Finite Element Method Models

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Analysis of aerospace structures is frequently conducted using nominal dimensions and frequently assumes ideal conditions in loading, contact, constraints, et cetera. Off-nominal dimensions and nonideal conditions, however, are present in all structures. These are the result of widely ranging causes from coefficient of thermal expansion mismatches, manufacturing tooling anomalies, to assembly procedures that inadvertently alter the structure. Specifically, geometric imperfections can have potentially significant influence on the response of a structural test article observed in an experiment versus the response given by a numerical simulation.

The Python Tool for Implementing Geometric Imperfections in Reduced Structures (Py_TIGIRS) was previously presented as a set of Python scripts to calculate and implement as-manufactured geometric midsurface and thickness imperfections into finite element method (FEM) shell models of nominally right circular cylinders. By taking advantage of the simple shape of a right circular cylinder, interpolations of the measured data points were able to be performed along directions that aligned to the cylindrical coordinate system axes of the entire structure. By taking advantage of the shell representation of the real structure as opposed to modeling using a continuum representation, the thickness variation was able to be implemented by shell section definitions instead of having to modify the position of multiple nodes in the thickness direction.

Py_TIGIRS is a useful tool that established a procedural example on how to implement geometric imperfections in right circular cylindrical shell structures. Three new procedures, each expanded from concepts established in Py_TIGIRS, are proposed for various test-article designs and are intended to broaden the range of structures that can be modeled with measured geometric imperfections in the structural analysis community. Each test-article design introduces new challenges to successfully implement geometric imperfections into a FEM model.

The first test-article design consists of a carbon fiber reinforced polymer square plate with a hat-shaped stiffener co-cured on one side. This test-article design was for a novel seven-point bend test that was also previously presented. Manufacturing and cure-cycle imperfections are observed using digital image correlation (DIC) techniques. As thermal expansion coefficient mismatches between the plate and stiffener materials were anticipated, a thermal analysis study with continuum shell and solid elements was conducted to capture the global shape observed prior to testing.

The second test-article design is of a similar hat-stiffened plate configuration, but with a side length ratio near 3:1 with elongation in the stiffener direction. The test article was used to characterize the response to uniaxial compressive loading in the direction of the stiffener. Due to differing manufacturing steps, a thermal analysis like the one developed for the seven-point bend configuration was unable to mimic the observed geometric imperfections. Instead, a strategy based on applying deformations directly to the structure during analysis was developed for continuum shell and solid element representation of a stiffened panel.

The third test-article design is a nominally flat sandwich composite design with a vertical bonded joint feature. The panel was manufactured with aluminum honeycomb core and carbon fiber facesheets. The imperfection implementation development associated with this configuration is a method to implement thickness and midsurface position imperfections in a model using continuum elements only. Procedures for interpolation and direct manipulation of nodal positions were developed to implement geometric imperfections in a continuum-element based FEM model.

Three test-article designs were studied to develop procedures to implement as-manufactured geometric imperfections into FEM models. Varying designs were considered so that each design presented a unique challenge to successfully implement geometric imperfections. Correlation between results of the three analyses and their respective test article's observed shape is to be discussed.

Bio:

Dr. Cyrus Kosztowny has been conducting research in the Structural Mechanics and Concepts Branch at NASA Langley Research Center since January 2017. His current NASA efforts are: investigating geometric imperfections in buckling-critical composite sandwich shells, postbuckling of stiffened structures, progressive damage of structural interfaces, fracture control plan test development for large-scale composite structures, and developing a mentoring culture at NASA Langley Research Center. His research interests include: structural stability, composite materials, manufacturing technologies, composite textile applications, and optimization of composite structures. Prior to joining NASA, Dr. Kosztowny was a NASA Space Technologies Research Fellowship recipient while at the University of Michigan where he received his Doctorate in Aerospace Engineering in the Spring of 2017.