

**APPLICATION OF THE NASA MULTISCALE ANALYSIS TOOL:
MULTISCALE INTEGRATION AND INTEROPERABILITY**

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INTEROPERABILITY**

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SUMMARY

The NASA Multiscale Analysis Tool (NASMAT) was developed recently to allow a wide variety of multiscale analysis problems to be effectively and efficiently solved. The architecture of NASMAT was established specifically to enable parallelized, “plug-and-play” functionality to reduce the complexity associated with adding new features to the code in the future and to allow end users to rapidly implement and evaluate user-defined capabilities. Additionally, the tool utilizes recursive data structures and subroutines to allow for an arbitrary number of length scales when performing multiscale analyses of heterogeneous materials. These features permit the rapid integration of user-defined capabilities (e.g., a material model, micromechanics approach, or failure theory) at all stages within a NASMAT calculation while leveraging built-in techniques where needed. Additionally, these features allow NASMAT to both be called from an external program as well as call an external program. This paper specifically focuses on the multiscale integration and interoperability of NASMAT with other analysis techniques through an illustrative, multiscale analysis of a 3D woven polymer matrix composite (PMC).

1: Overview of NASMAT

The NASA Multiscale Analysis Tool (NASMAT) is a state-of-the-art, parallelized, “plug-and-play”, computational platform for performing multiscale analysis of heterogeneous materials. The software architecture was developed while keeping the following key ideas in mind: code utility, upgradability, maintainability, and interoperability. As a result, recursive procedures, subroutines, and data structures were

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developed that allow an arbitrary number of scales to be defined and seamlessly pass data between each other. This idea forms the foundation of the Multiscale Recursive Micromechanics approach (MsRM) utilized in this paper. Furthermore, NASMAT was designed to be modular such that a user would have the ability to integrate a micromechanics, material, damage, or failure model, for example, with minimal effort. In doing so, the user would retain access to all other supported features. To demonstrate the functionality and capability of the software, a multiscale analyses of a 3D woven PMC was performed.

2: Multiscale Analysis of a 3D Woven PMC with Damage

In this example, a multiscale model of an AS4 carbon fiber/ RTM6 epoxy matrix 3D orthogonal woven PMC was generated and compared to available test data [1]. The presence of voids in the bulk matrix was also included in the model. The woven architecture is shown in Figure 1a where matrix subcells have been hidden for clarity. X-ray computed tomography was performed to generate a set of nominal tow sizes and spacings. Figure 1b contains the multiscale modelling strategy for analyzing this 3D woven composite. Through a series of localization operations, successively lower levels are called until ultimately the individual fiber, matrix, and void constituents are reached. Once a constituent material is reached at any level, no further localizations can occur. Once all localizations have occurred for a given level, field values and properties are then homogenized and passed up to the previous level. In this multiscale approach, the textile architecture is modeled using the three-dimensional Generalized Method of Cells (GMC3D) micromechanics theory, the tows are modeled using the two-dimensional GMC (GMC2D) micromechanics theory with a hexagonal arrangement of fibers, and the bulk matrix (matrix plus voids) is modeled using the Mori-Tanaka mean-field micromechanics theory [2]. Level 1 and Level 2 represent a two-step homogenization procedure using the GMC3D micromechanics theory similar to the one adopted in Ref. [1]. Maximum stress and maximum strain failure criteria were specified for the fiber constituent in both tension and compression, and a maximum stress failure criterion was specified for the matrix (same in tension/compression) based on literature data [3-4]. The predicted warp-direction (x_3) stress/strain curve is compared to experimental data in Figure 2. Good agreement between the simulated and experimentally observed stress/strain curves were obtained with minimal analysis assumptions. The predicted warp-direction tensile modulus (59.3 GPa) and tensile strength (753 MPa) are both within 3% of experimental data [1]. Furthermore, this NASMAT analysis performed 100 loading increments in roughly 30 seconds, a significant computational cost savings over high-fidelity finite element analyses. The predictive capability of NASMAT

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combined with its speed provides an attractive tool for performing rapid engineering trade studies of complex composite systems. This example also demonstrated NASMAT's flexibility by incorporating five separate levels of calculations and three distinct micromechanics theories under one platform.

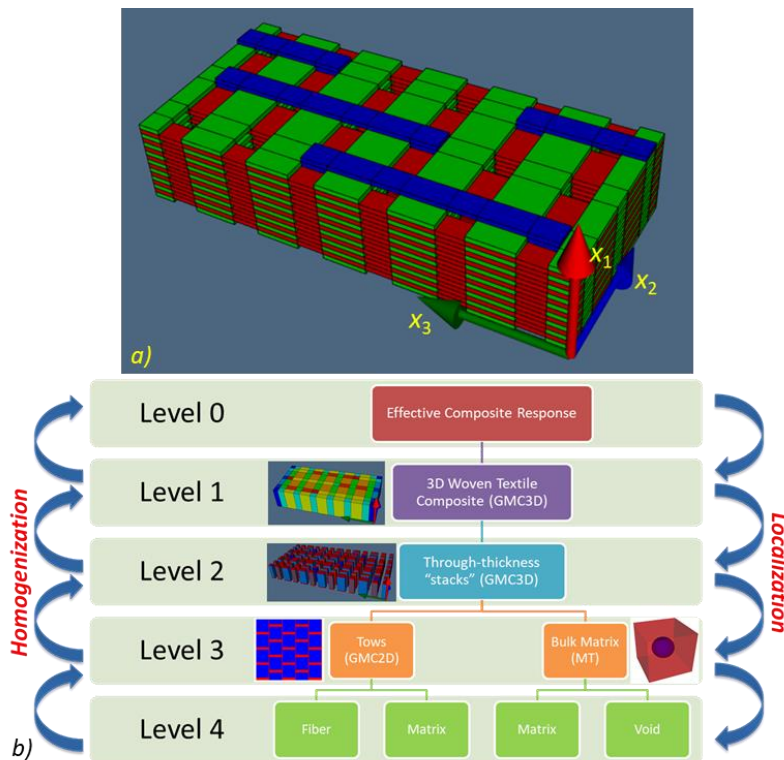


Figure 1: a) GMC3D discretization of a 3D orthogonal composite with matrix subcells hidden and tow materials shown (red-warp, green-weft, blue-binder) and b) multiscale scale modeling strategy

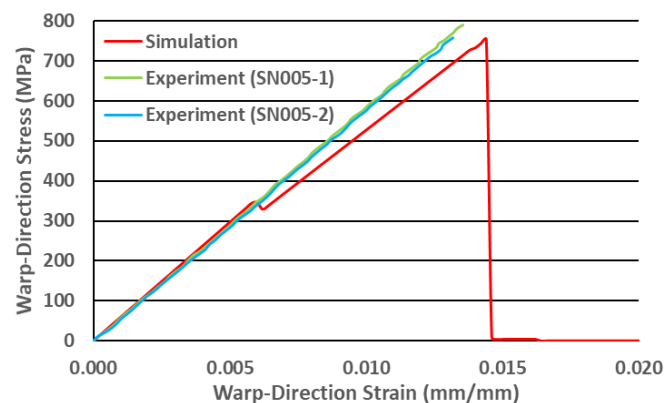


Figure 2: Warp-direction stress/strain response of a 3D woven composite. Experimental data from Ref. [1].

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3: Release and Upcoming Features

The first public release of NASMAT (version 2.0) is expected to be October 2020. In addition to the capabilities described in the example above, support will be available for the Macroscale Application Programming Interface (MacroAPI - the interface used to connect NASMAT with an external software), classical lamination theory, three additional micromechanics techniques (High-Fidelity GMC2D (HFGMC2D), Parametric HFGMC2D (PHFGMC2D), Carrera Unified Formulation (CUF)), a viscoplastic material model, a progressive damage model, and multiscale data output via HDF5. Furthermore, enhanced tools to visualize multiscale data are expected to be separately released.

4: Acknowledgments

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