Current Capabilities and What's New in MAC/GMC 4.0

The current capabilities of MAC/GMC are listed below, with new or improved features in this version highlighted in bold blue type. The superscripts refer to the enumerated details regarding these new features given after the list.

Current Capabilities

- **User Interface**[1]
  - **Intuitive ASCII user interface** (note that a graphical user interface (GUI) for MAC/GMC 4.0 is in development)

- **Computer Resource Management**[2]
  - **Dynamic memory allocation**
  - **Static problem size limitations removed**
  - **Improved efficiency of solution for laminate analysis and large problems**

- **Material Constitutive Models**[5]
  - Elastic: isotropic, transversely isotropic, **completely anisotropic**
  - Inelastic: Bodner-Partom, **Robinson**, isotropic GVIPS, transversely isotropic GVIPS, **multimechanism GVIPS**, **SMA**, **incremental plasticity**, **Freed-Walker**.
  - User-defined: user-defined constitutive model subroutine (`usrmat.F90`)

- **Library of Material Properties**
  - Expanded internal material property library
  - User-defined subroutine (`usrfun.F90`) for calculating material properties as a function of temperature or other variable
  - **External material property database file**[5]

- **Micromechanics Analysis Models**
  - Doubly periodic generalized method of cells
  - Triply periodic generalized method of cells
  - Doubly Periodic **High-Fidelity Generalized Method of Cells (HFGMC)**[4]

- **Laminate Analysis Model** (Classical Lamination Theory)
  - Monolithic layers
  - Doubly periodic composite layers
  - **Triply periodic composite layers**[7]

- **Electromagnetic "Smart" Material, Composite, and Laminate Analysis**[3]

- Library of Repeating Unit Cell Architectures

- **Library of Applied Loading History Options**

- Thermal, uniaxial, biaxial, general (arbitrary) loading, thermo-mechanical
- **Curvature and moment loading for laminate**
- **Electromagnetic loading**

- Time Integration Options
  - Forward Euler
  - Self-Adaptive Predictor-Corrector

- **Yield Surface Analysis**[8]
  - GMC, **HFGMC**, **laminate**
  - Global (composite level), **local (subcell level)**, **ply level in laminate**

- **Elastic Allowables Estimation**[9]

- **Static Failure Analysis**[9]
  - Doubly periodic GMC, **triply periodic GMC**, **laminate**
  - Subcell level, **repeating unit cell level**
  - Max. stress, Max. strain, **Tsai-Hill**

- **Interface Modeling**
  - Distinct interfacial phase layer
  - Interfacial displacement discontinuity modeling (GMC and **HFGMC)**

- **Fiber Breakage**[12]
  - Using internal fiber interface
  - **Curtin effective fiber breakage model**

- **Fatigue Damage Analysis**[10]
  - Doubly periodic GMC, **triply periodic GMC**, **laminate**
  - Stiffness reduction, **strength reduction**
  - **Can be combined with static failure, debonding, and fiber breakage**

- **Output and Data Visualization**[13]
  - **Unilimited number** of macro, micro, and laminate x-y plot files
  - PATRAN output for use with the MACPOST software add-on → fringe plots
  - **MATLAB output for use with distributed MATLAB source files** → fringe plots

- **Example Problems**
  - **43 new example problems** are distributed with the code and described in the Example Problem Manual

Details on New Features in MAC/GMC 4.0

1) The format of the MAC/GMC 4.0 input file has been completely overhauled. Unneeded keywords have been eliminated, more logical keyword and specifier names have been utilized, and the placement of specific data has been better organized. The result is a considerably more streamlined and easy to use input file format.

2) The memory allocation of MAC/GMC 4.0 is dynamic. There is no longer a static limit on the size of the problem (i.e., number of subcells and laminate plies) that can be analyzed, the number of constituent materials that can be employed, or the number of x-y plot result files that can be analyzed. The result is a more robust code that only uses the system resources it needs to execute a given problem.

3) MAC/GMC 4.0 can analyze smart composites and laminates. A major advancement in the generalized method of cells micromechanics models and lamination theory has been implemented within MAC/GMC 4.0: the ability to model fully coupled thermo-electro-magneto-visco-elasto-plastic composite materials and laminates. These so-called "smart" materials and composites react electromagnetically to thermo-mechanical loading and react mechanically to electromagnetic loading. These materials are currently finding a growing number of applications in sensors and actuators and have the potential to enable the next generation of multi-functional structures that can automatically sense and react to various stimuli.

4) A new high-fidelity doubly periodic micromechanics model has been implemented within MAC/GMC 4.0. This new micromechanics model, the high-fidelity generalized method of cells (HFGMC) provides much more accurate local stress and strain field predictions than does the standard method of cells. MAC/GMC 4.0 can therefore perform composite analyses with a variable level of fidelity, maximizing either accuracy or efficiency when appropriate.

5) Several new internal material constitutive models have been implemented within MAC/GMC 4.0. These include: a shape memory alloy constitutive model, the classical incremental plasticity model, a new multimechanism visco-elastic-plastic GVIPS model, the Freed-Walker viscoplasticity model, a Robinson special viscoplasticity model for NARloy Z, and a completely anisotropic elastic model. The classical incremental plasticity model is formulated to allow the user to simply input stress-total strain point pairs from a material's inelastic stress-strain curve.

6) MAC/GMC 4.0 enables the use of an external material database file. User's can store their own material properties in this external database file, from which the code reads and stores only the material properties specified for use in a specific problem.

7) The laminate analysis capabilities have been significantly expanded and computationally enhanced. Discontinuous fiber and particulate reinforced laminate layers can now be analyzed thanks to the ability of triply periodic GMC to represent any particular layer within a laminate. Further, all laminate data is now kept in core memory during execution (previous

versions of MAC/GMC performed read/write cycles to disk). This has significantly increased the computational efficiency of MAC/GMC 4.0 laminate analyses.

8) The yield surface analysis capabilities of MAC/GMC 4.0 are significantly expanded. Various subcell and repeating unit cell level yield surfaces can be automatically generated for composites using standard or high-fidelity GMC. Further, yield surfaces can now be automatically generated for laminates on the laminate, ply, and micro (subcells within a ply) levels.

9) The static failure analysis capabilities of MAC/GMC 4.0 have been significantly enhanced. A simple and quick estimation of composite allowable stress and strain quantities can be performed based on the constituent allowables. Further, true subcell and repeating unit cell level static failure analysis (i.e., checking for failure at various scales during application of simulated thermo-mechanical loading) can be performed using several failure criteria. These failure analyses are available for composites as well as laminates.

10) The fatigue damage analysis capabilities of MAC/GMC 4.0 have been significantly enhanced. A new strength reduction fatigue model has been implemented, and the applicability of the stiffness reduction fatigue model has been expanded to include triply periodic repeating unit cells and laminates. Further, both fatigue damage models now work in concert with the MAC/GMC 4.0 static failure and interfacial debonding capabilities to enable mechanistically realistic life predictions for composites and laminates.

12) The local fiber failure analysis capabilities of MAC/GMC 4.0 have been improved via inclusion of the Curtin effective fiber breakage model. Based on fiber strength statistical data, the Curtin model is a widely used tool for predicting composite stiffness degradation and failure due to longitudinal fiber fracture. The Curtin model can be used to model fibers within continuous fiber composites and continuous fiber composite layers within laminates.

13) The post-processing of MAC/GMC 4.0 results has been significantly improved. The code now automatically generates output for use with the popular MATLAB software package. MATLAB source files are distributed with MAC/GMC 4.0 that generate fringe plots of the stress, strain, and inelastic strain fields predicted by MAC/GMC 4.0.

14) MAC/GMC 4.0 has been extensively tested and debugged.