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TEXCAD - TEXTILE COMPOSITE ANALYSIS FOR DESIGN[1]

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INTRODUCTION

The Textile Composite Analysis for Design (TEXCAD) code provides the materials/ design engineer with a user-friendly, desktop computer based tool for the analysis of a wide variety of fabric reinforced woven and braided composites. It can be used to calculate overall thermal and mechanical properties along with engineering estimates of damage progression and strength. TEXCAD also calculates laminate properties for stacked, oriented fabric constructions. It discretely models the yarn centerline paths within the textile repeating unit cell (RUC) by assuming sinusoidal undulations at yarn cross-over points and uses a yarn discretization scheme (which subdivides each yarn into smaller, piecewise straight yarn slices) together with a 3-D stress averaging procedure to compute overall stiffness properties. In the calculations for strength, it uses a curved beam-on-elastic foundation model for yarn undulating regions together with an incremental approach in which stiffness properties for the failed yarn slices are reduced based on the predicted yarn slice failure mode. Nonlinear shear effects and nonlinear geometric effects can be simulated. Input to TEXCAD consists of: (i) material parameters like impregnated yarn and resin properties such as moduli, Poisson's ratios, coefficients of thermal expansion, nonlinear shear parameters, axial failure strains and in-plane failure stresses; and (ii) fabric parameters like yarn sizes, braid angle, yarn packing density, filament diameter and overall fiber volume fraction. Output consists of overall thermoelastic constants, yarn slice strains/stresses, yarn slice failure history, in-plane stress-strain response and ultimate failure strength. Strength can be computed under the combined action of thermal and mechanical loading (tension, compression and shear).

A brief overview of the analytical capabilities, program organization and modules, input and output parameters, computer platforms, distribution, and, modifications/extensions of the TEXCAD code is presented here.

[1]This work was performed under Contract Numbers NAS1-19399, NAS1-19708.

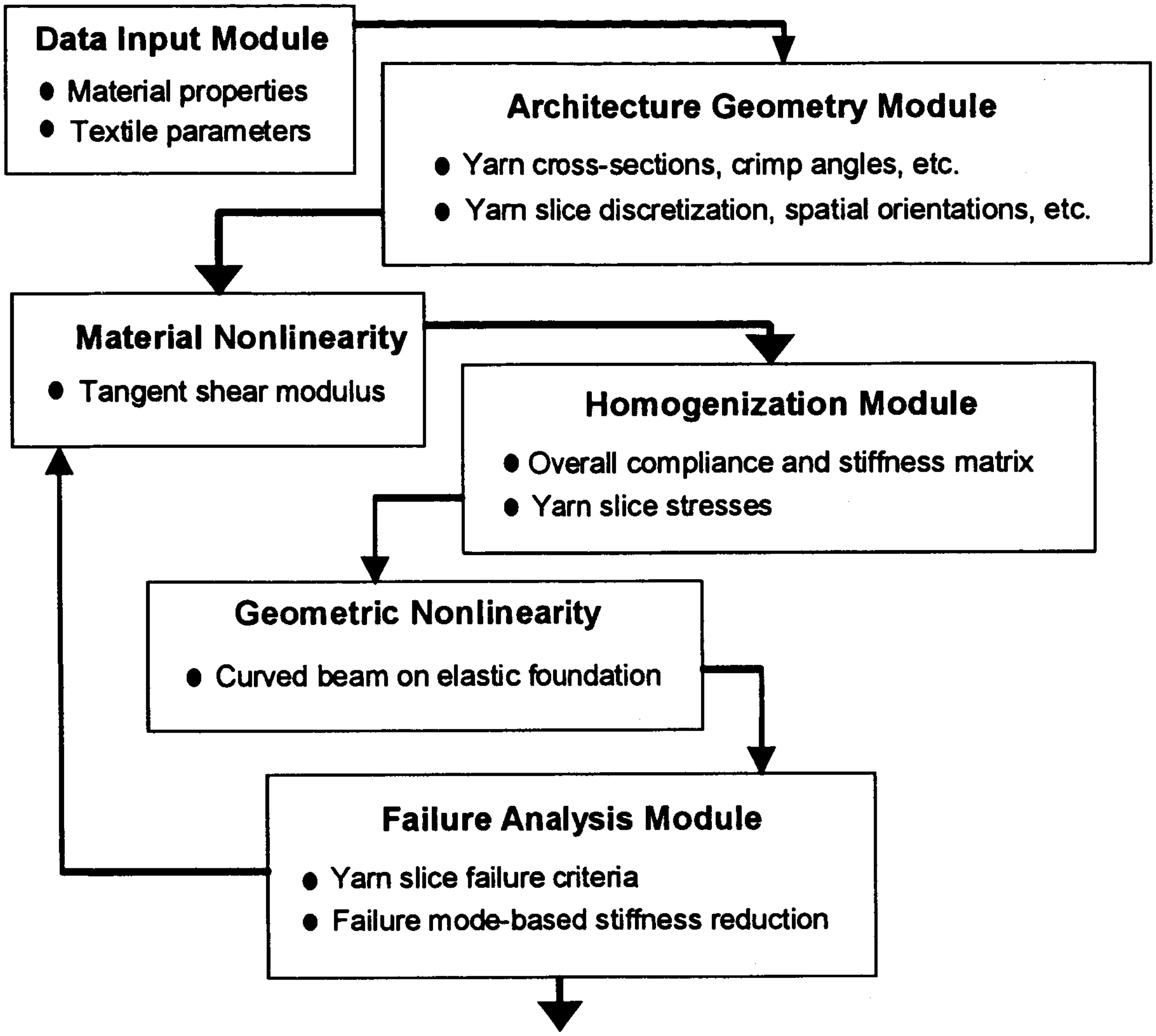
Analysis Capabilities

- Three-dimensional Stiffnesses
- Coefficients of Thermal Expansion (CTE's)
- Thermal and Mechanical Stresses
- Progressive Damage
- Nonlinear Geometric and Material Response
- Strengths
  - Tension (longitudinal and transverse)
  - Compression
  - Shear

Textile Architecture Models

- Weaves
  - Plain
  - 5-harness satin
  - 8-harness satin
- Braids
  - 2-D
  - Triaxial (1x1, 2x2)
  - 3-D multi-interlock
  - 3-D, 4-step (under development)
- Custom architectures

TEXCAD Organization and Modules

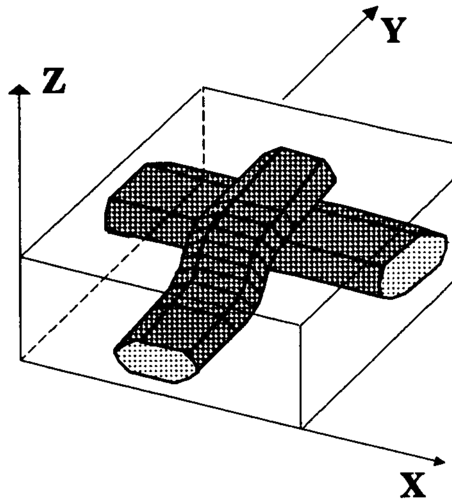


TEXCAD Input Parameters

- **Braid angle**
- **Yarn filament counts**
- **Filament diameter**
- **Yarn packing density**
- **Yarn and resin material properties**
- **Composite fiber volume fraction**

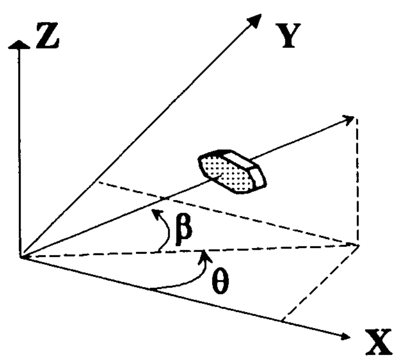
GEOMETRIC MODELING OF YARNS

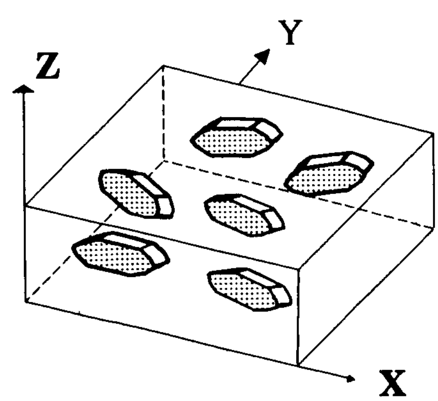
- Yarn cross-section is a flattened lenticular shape and remains constant along yarn path.
- A yarn is approximated by piecewise straight slices.
- Yarn follows a sinusoidal path at a cross-over point.
- Volume not occupied by yarns is assigned to interstitial matrix.



MULTI-DIRECTIONAL COMPOSITE MODEL FOR TEXTILES

- Each yarn slice described by orientation angles θ and β and by its volume fraction.
- RUC assumed to be a multi-directionally reinforced composite.
- Internal stresses calculated by assuming an iso-strain state within RUC.
- Stiffness calculated by volume averaging of internal stresses in yarn slices and interstitial matrix.





NON-LINEAR SHEAR RESPONSE

- A three parameter equation [Richard and Blacklock, 1969] was used to represent material non-linearity under shear:

$$\tau_{12} = \frac{G_{12}\,\gamma_{12}}{\left[1 + \left(\frac{G_{12}\,\gamma_{12}}{\tau_{12}^{ult}}\right)^{m}\right]^{\frac{1}{m}}}$$

- Based on curve-fits to experimental data $\underline{m = 2.78}$ for AS4/3501-6 tape laminates and $\underline{m = 2.34}$ for 3501-6 resin.

OVERALL THERMO-ELASTIC CONSTANTS

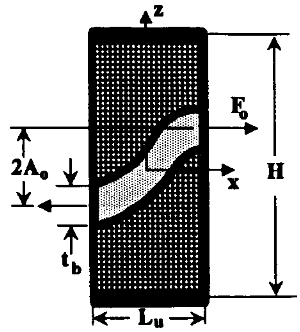
- The overall stiffness matrix $[C_{eff}]$ is determined by volume averaging of the yarn slice stresses and is given by:

$$[C_{eff}] = \sum_{k=1}^{N}\left(V_k [T]_k^T [C']_k [T]_k\right)$$

- The effective coefficients of thermal expansion are given by:

$$[\bar{\alpha}] = \left[C_{eff}\right]^{-1}\left\{\sum_{k=1}^{N}\left(V_k [T]_k^T [C']_k \{\alpha'\}_k\right)\right\}$$

YARN BENDING ANALYSIS



- Initial Sinusoidal Yarn Path: $\bar{w} = A_o \sin(\frac{\pi x}{L_u})$
- Assumed Deformation: $w = A_1 \sin(\frac{\pi x}{L_u})$
- A_1 determined by Min. Potential Energy Theorem:

$$\frac{\partial(U - W)}{\partial A_1} = 0$$

$$\beta = \frac{\pi}{L_u}$$

$$A_1 = \frac{-E_o \beta^2 A_o}{E_{11} I \beta^4 + E_o \beta^2 + k}$$

k - from Lee and Harris, 1990

- For Geometric Non-linear Analysis: $A_o^{i+1} = A_o^i + A_1^i$

$$L_u^{i+1} = L_u^i (1 + \varepsilon_x^i)$$

- This model is used only for estimating yarn strains in the x-z plane.

FAILURE CRITERIA

Yarn Failure:

- ***Max. stress criterion*** **to predict following failure modes:**
  - **Transverse tension (σ_{22}, σ_{33})**
  - **Transverse shear (τ_{23})**
  - **Longitudinal shear (τ_{12}, τ_{13})**

- ***Max. strain criterion*:**
  - **Axial yarn failure under tension/ compression**

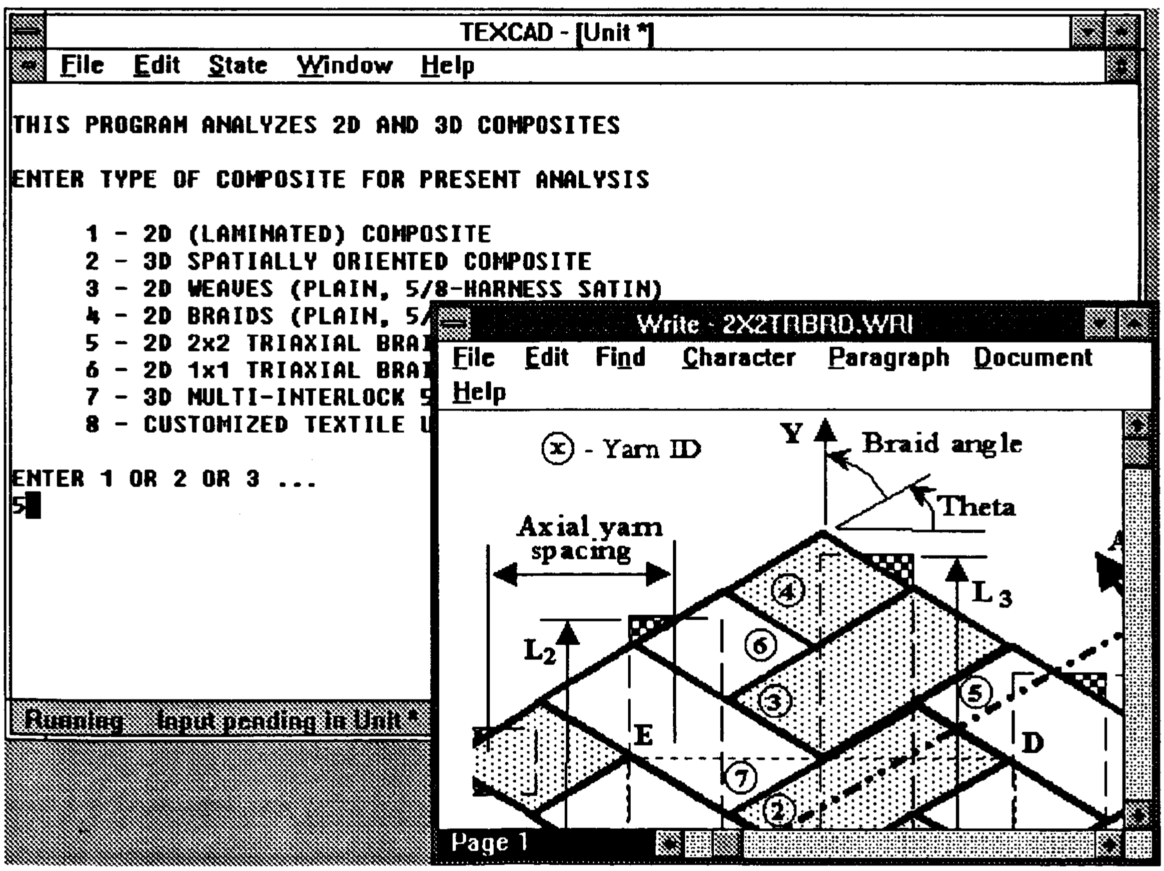
Matrix Failure:

- ***Maximum principal stress criterion*** **($\tau_{12} = 0$).**
- ***Von Mises octahedral shear stress criterion*** **($\tau_{12} \neq 0$).**

TEXCAD Output

- Yarn geometry, crimp angles, etc., for each yarn
- Overall stiffness and compliance matrix
- Unit cell three dimensional stiffnesses and CTE's
- Mechanical and thermal stress/strain in all yarns
- Composite stress-strain response
- History of failure stress and mode of failed yarn slices

The TEXCAD user interface under the Microsoft Windows environment



TEXCAD Computer Platforms

- IBM PC compatibles
  - DOS
  - Microsoft Windows
- Apple Macintosh
- UNIX Workstations

TEXCAD Documentation

- TEXCAD User's Manual
- TEXCAD Theory Manual I - NASA CR-194930, June 1994.
- TEXCAD Theory Manual II - NASA CR-194981, Sept. 1994.
- Publication:

  Journal of Composite Materials, Vol. 28, No. 7, 1994
- Presentations:

  NASA/DoD ACT Conference, Salt Lake City, June 1993

  ASTM 12th Symposium on Composite Materials: Testing and Design, May 1994

  NASA/DoD ACT Conference, Seattle, August 1994

Collaborations

- **Lockheed, Georgia** - ***Bharat Shah, Kwoon Young***
  - Development of TEXCAD for Hybrid 2-D Triaxial Braids.
- **North Carolina A&T State University** - ***Prof. A. D. Kelkar,*** Graduate Student: ***Dwayne Crawford***
  - Development of a 3-D Finite Element Model for 2-D Triaxial Braids using TEXCAD Geometry Module.
- **North Carolina A&T State University** - ***Prof. K. N. Shivakumar,*** Graduate Student: ***Kevin Branch***
  - Development of a TEXCAD Geometry Module for 3-D, 4-Step, Circular Braids.
- **University of Florida** - ***Prof. B. V. Sankar and Prof. P. G. Ifju***
- **Lockheed Engineering and Sciences** - ***Dr. J. E. Masters***

TEXCAD Distribution

Industry

- **Lockheed, Georgia**
- **GE Aircraft Engines and GE R&D**
- **Pratt & Whitney**
- **Beech Aircraft**
- **Atlantic Research Corporation**
- **Fiber Innovations**
- **Dow United Technologies**
- **Boeing Defense Space Group**
- **Martin Marietta**
- **McDonnell Douglas Helicopter**
- **Alliant Techsystems**

University

- **Virginia Tech**
- **Iowa State University**
- **North Carolina A & T**
- **Wichita State University**
- **Boston University**
- **Florida Atlantic University**

Government

- **Wright Laboratories, WPAFB**

SUMMARY

- A general-purpose analysis for stiffness, damage-progression, and strength of textile composites was developed and implemented in the user-friendly TEXCAD code.

- Documentation in the form of a User's Manual and theory manuals was completed.

- A number of evaluation copies of TEXCAD were distributed to users in industry, government and university.