Experimental Validation of a Kevlar Fabric Model for Ballistic Impact

Chian-Fong Yen
Tusit Weerasooriya
Paul Moy
Brian Scott
Bryan Cheeseman
ARL, APG MD

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

International Symposium on Ballistics
New Orleans, LA
26 September 2008

Outline

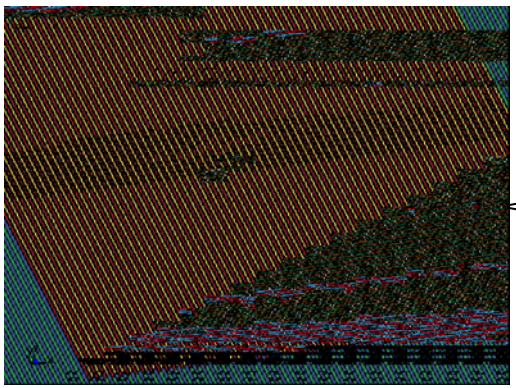
- Experimental Studies
  - Ballistic impact of single layer fabric
- Fabric Modeling
  - Yarn level model
  - Sub-yarn level model*****
- Conclusions

***** Including results reported in the poster #198 entitled: "**Developing Simulation Capabilities to Link Textile Manufacturing to Ballistic Performance"** by B.A. Cheeseman*, C.F. Yen, B.R. Scott, B. LaMattina, Y. Miao and Y. Wang

Modeling Approach

- Assess current state-of-the-art modeling capabilities and determine the most suitable numerical analysis techniques
- Develop and implement the identified analyses techniques
- Validate analyses techniques with high resolution experiments. Refine modeling capabilities as necessary to ensure the accuracy of the simulation when compared to the experiment

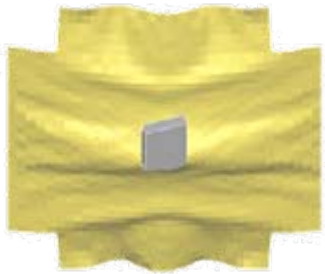
Modeling of Fabrics

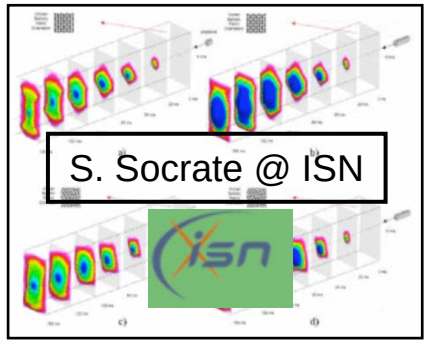


'…the ballistic response of the textile structure depends on the response of the fiber with which it is woven as well as the structural geometry itself." D. Roylance, *Text. Res. J. 1973.*

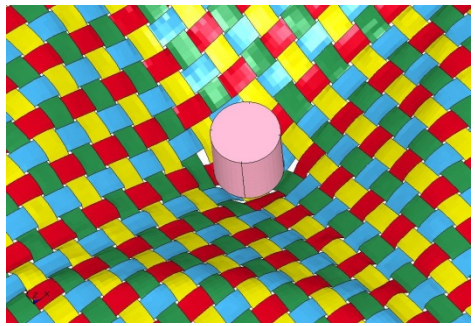
Fabric as a continuum

From Simons, J.W., Erlich, D.C. and Shockey, D.A. 20th Int. Symp.Ballistics, Nov. 2001

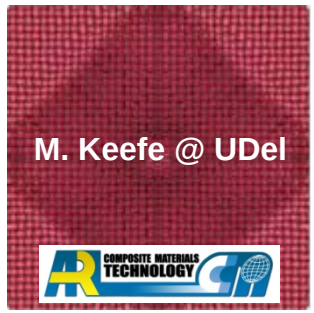




Yarn as a continuum

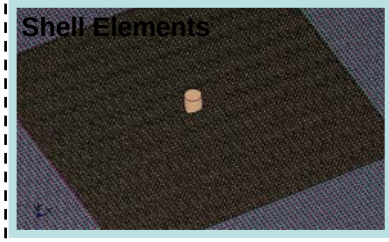


Solid Elements

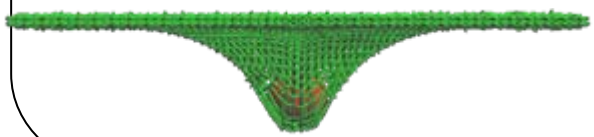


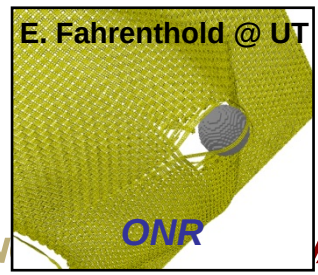
C. Yen

Shell Elements

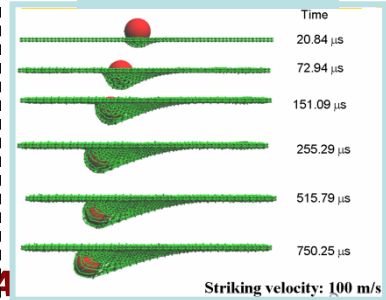


Filament as a continuum

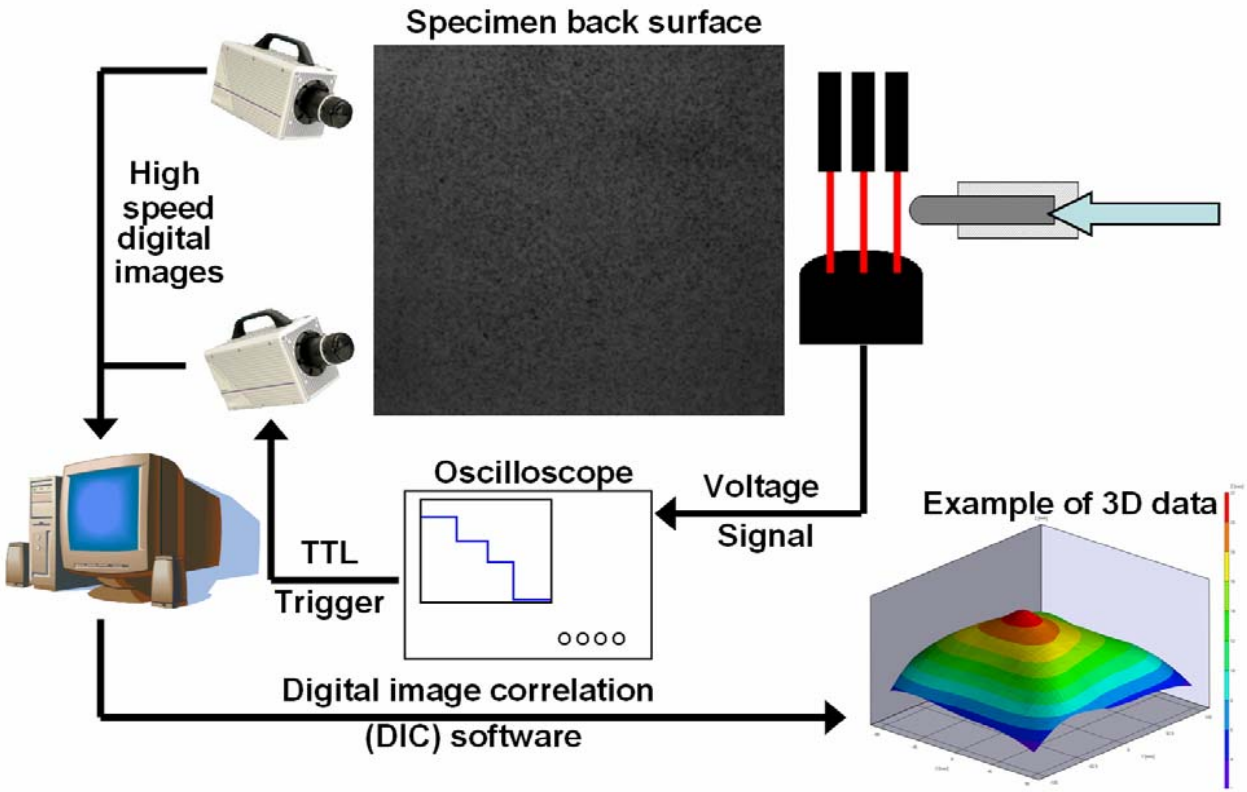


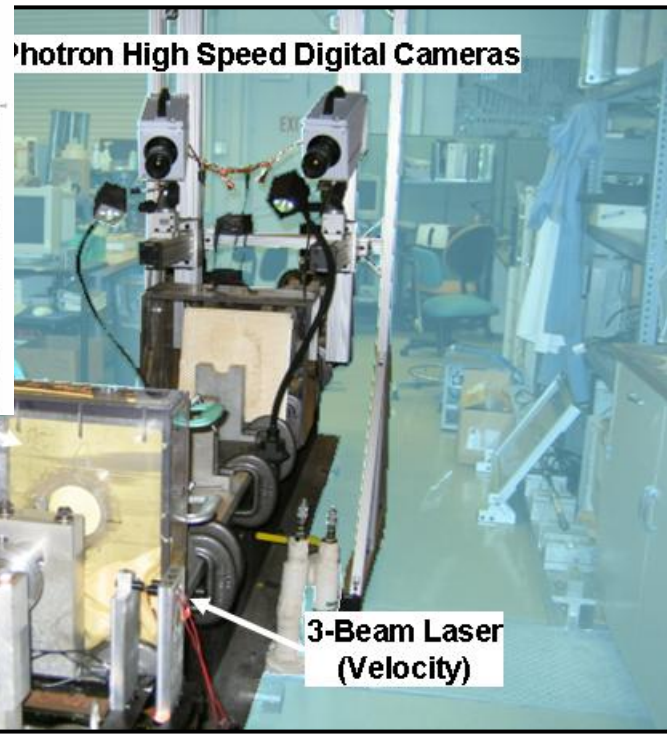


Y. Wang @ KSU



Fabric Impact Testing: Experimental Setup with High Speed Digital Cameras

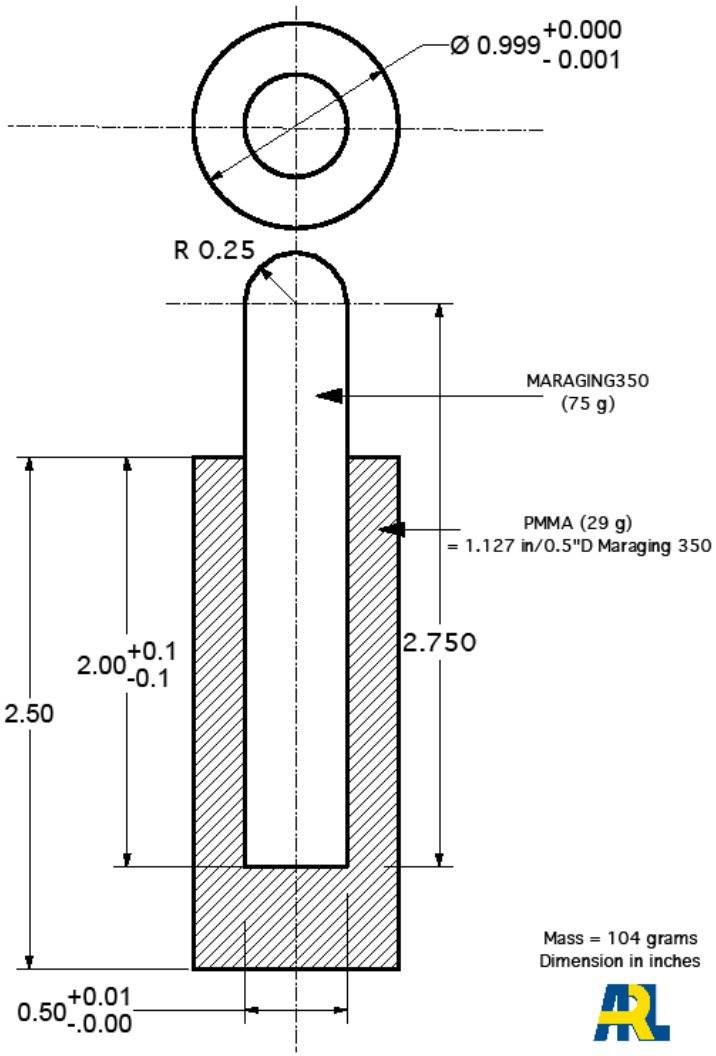




Fabric Impact Testing: Experimental Configurations

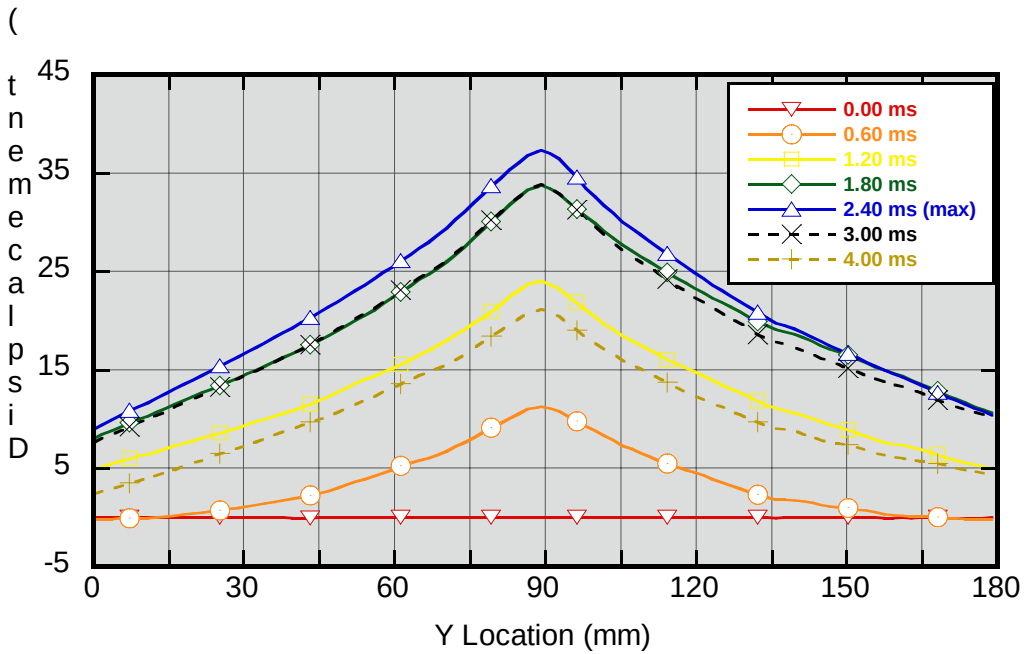
Experimental Results:
May, 2007
Tusit Weerasooriya
ARL

Target:
Hexcel Style 706
Single Layer
Square & Circular Shapes
10”x10” & Diameter = 10”
Fixed boundary
Impact Speed: 22.2m/s



IMPACTOR for DIC on Back Surface

Fabric Impact Testing: Results of Kevlar KM2 Fabric, Displacement Profile, Contours



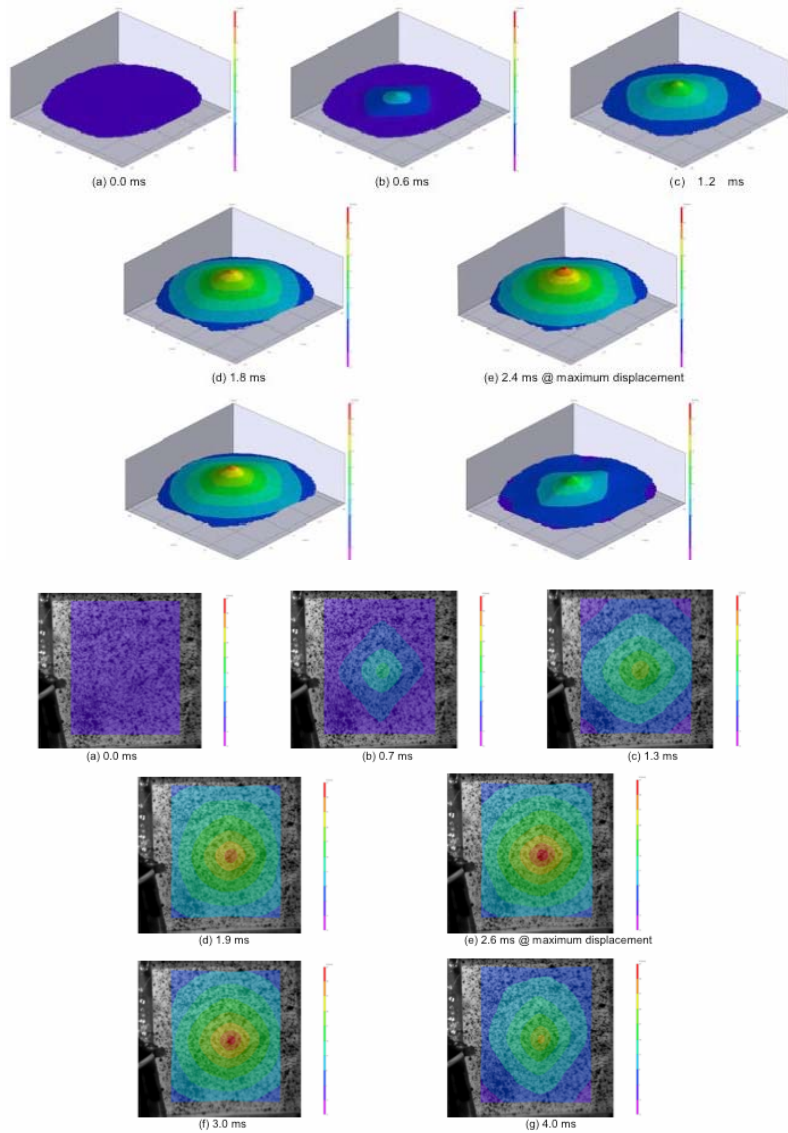
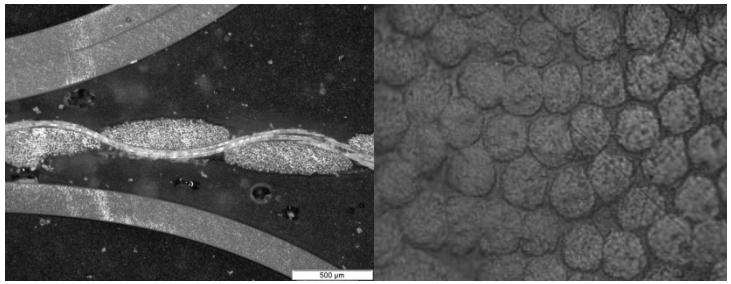


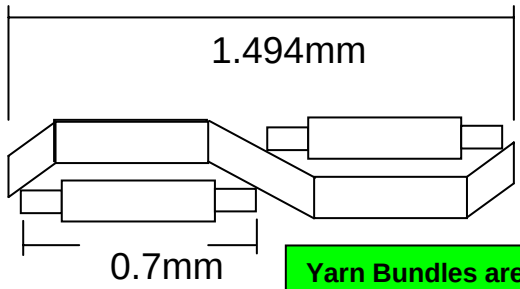
Figure 10. 2D Contour Plot from DIC of Kevlar KM2 on a Square Frame Configuration

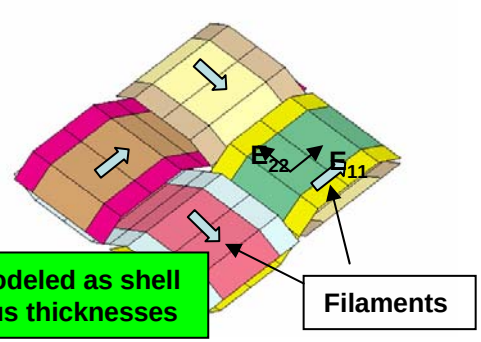
Yarn-Level Modeling Efforts

- **Improved the accuracy of yarn bundle shape and dimensions in a woven structure.**



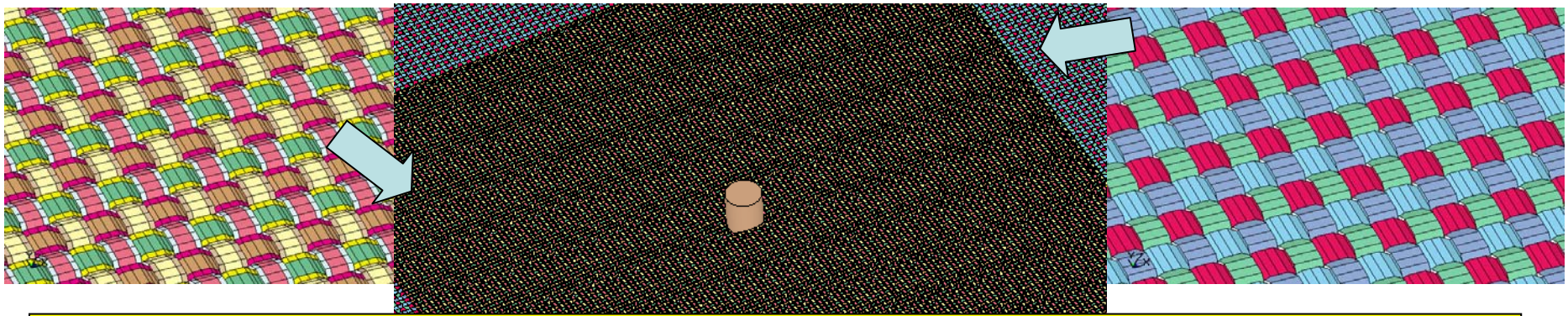
- **Obtained micrographs in order to get more accurate measurements.**





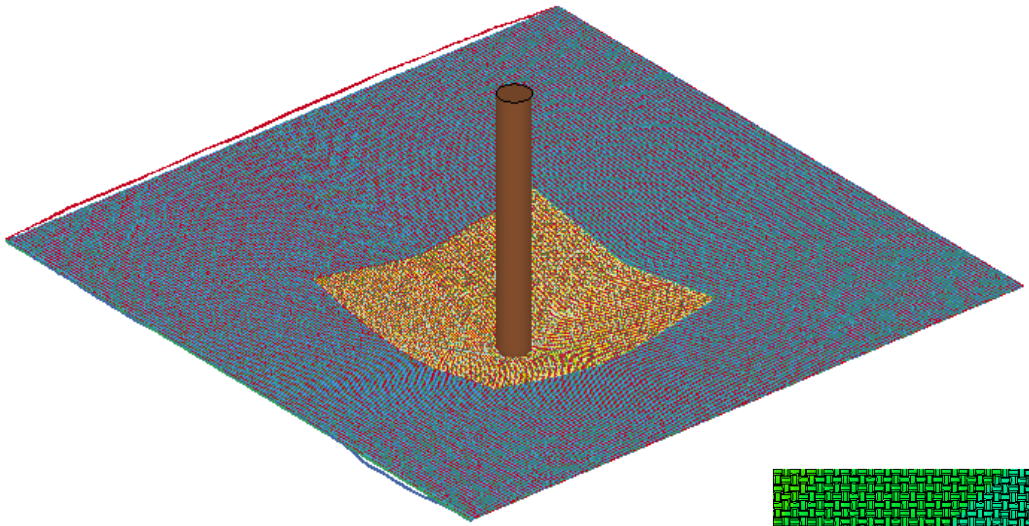
Yarn Bundles are modeled as shell elements with various thicknesses

- **Improved computational efficiency for shorter run times.**
- **Utilized refined mesh in region of impact; less refined elsewhere.**

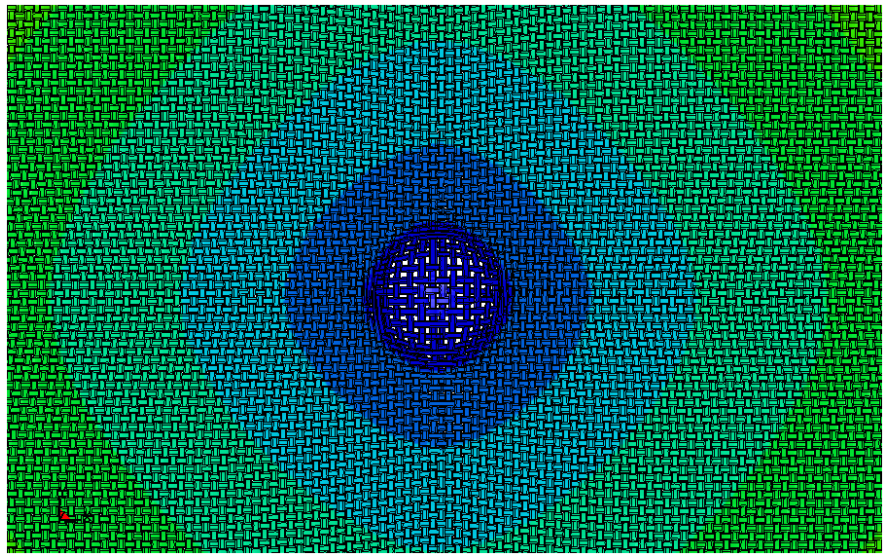


•Using one intg. pt. through bundle thickness to eliminate bundle bending rigidity
•High mesh density in center impact region

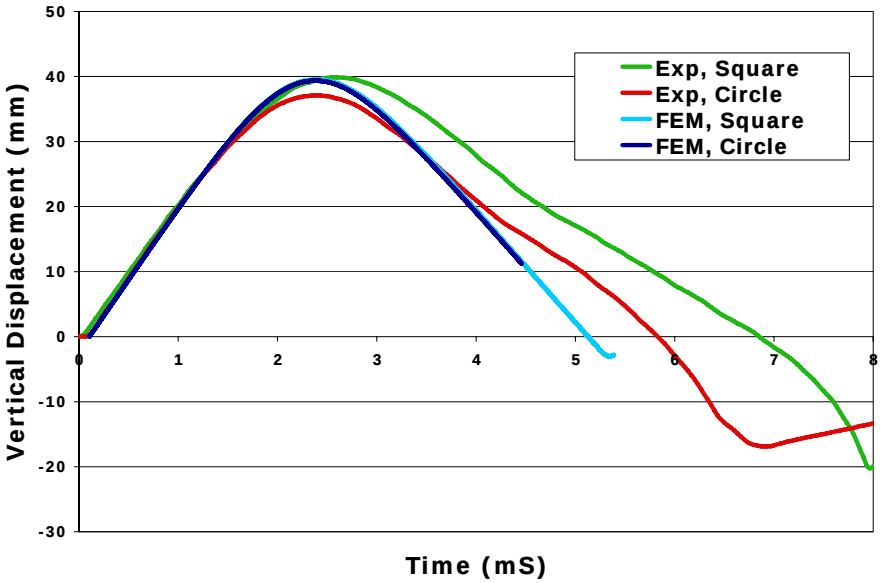
Yarn-Level Modeling: Simulation

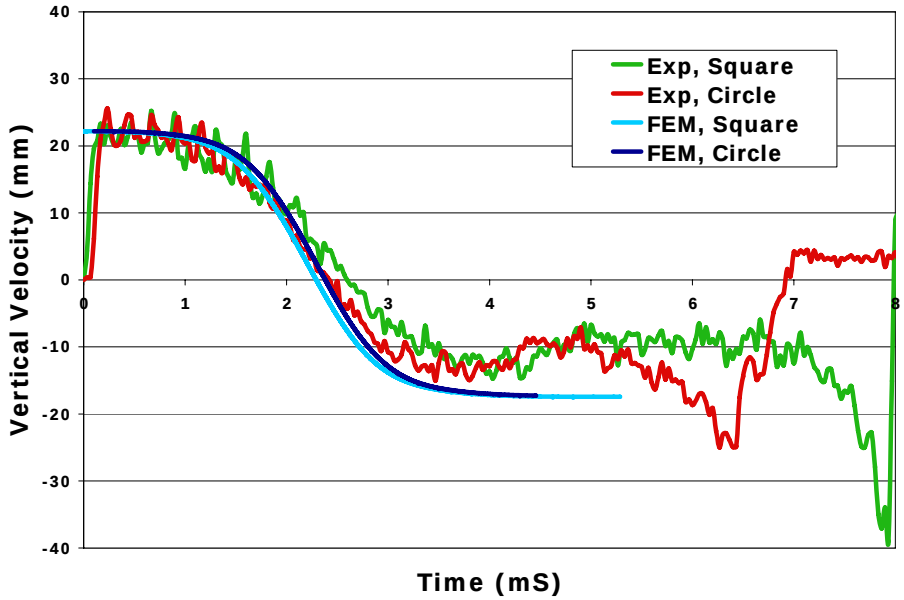


- Deformed mesh of a 34x34 Kevlar fabric layer computed at the peak deflection time of 2.3 msec



Yarn-Level Modeling: Correlation

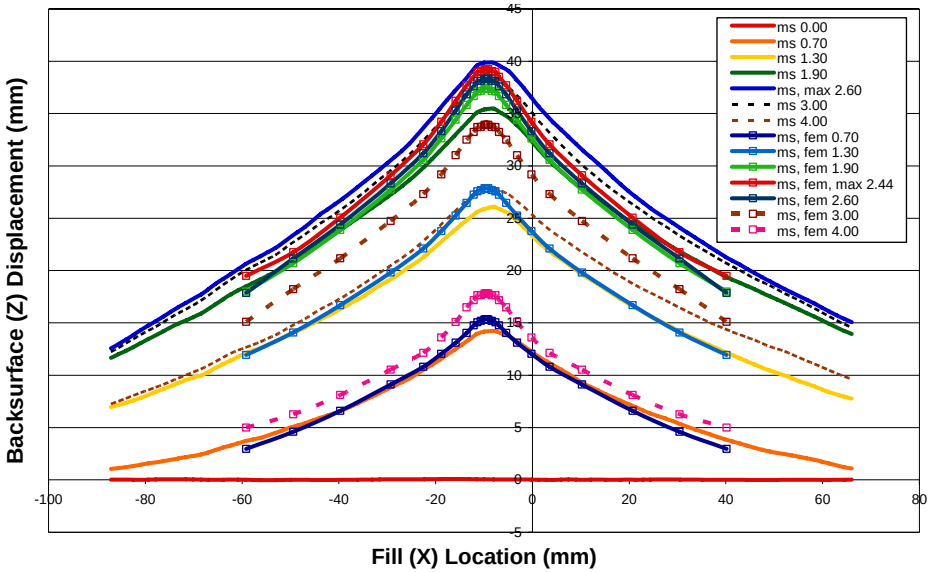




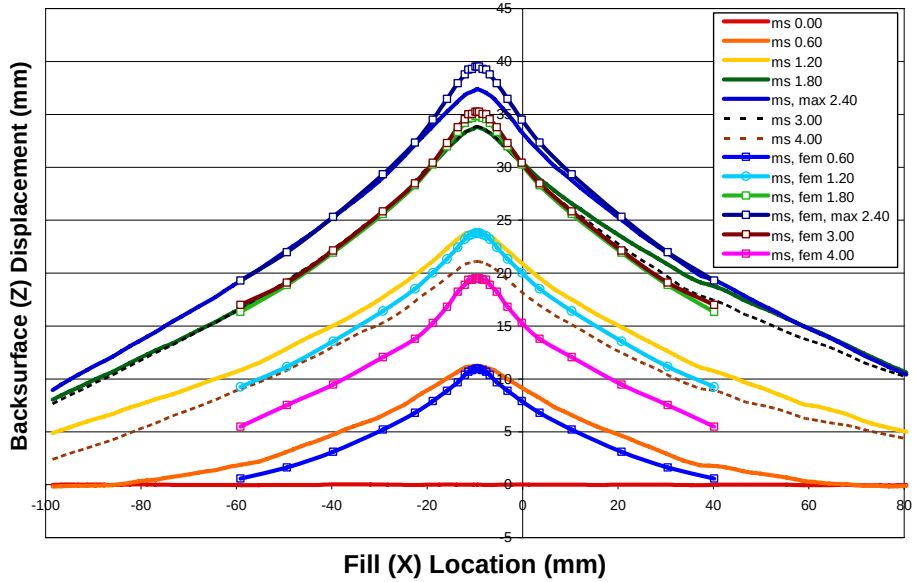
- Displacement -time and velocity – time plots of Kevlar KM2 yarn in weft (x) direction for square support and circular support through the impact point

Yarn-Level Modeling: Correlation

Square Fixture



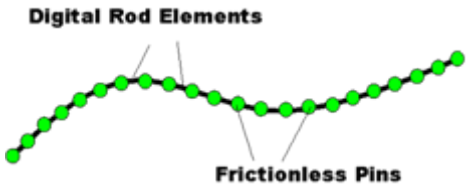
CircularFixture



- Displacement profile of Kevlar KM2 yarn in fill direction for square and circular frame configurations through the impact point

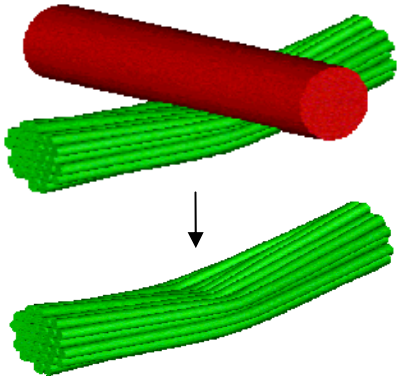
Computational Modeling of Ballistic Textiles: Sub-yarn Level Representation of Fabrics, Kansas State U., Youqi Wang

‘Filament’



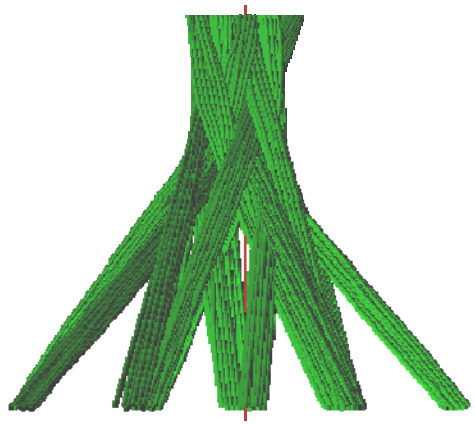
Represented as a series of rod elements connected with frictionless pins = ‘digital chain’

Yarn



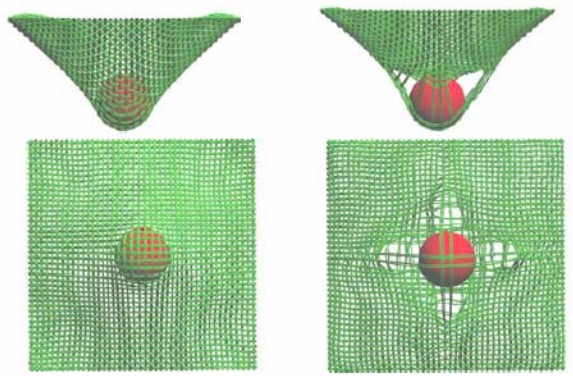
Multi-Digital Chain Yarn Model (Here, each yarn contains 32 digital chains)

Weave or Braid



Yarns utilized to simulate textile manufacturing process

Extended textile manufacturing simulation program to ballistic impact

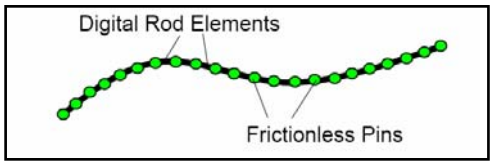


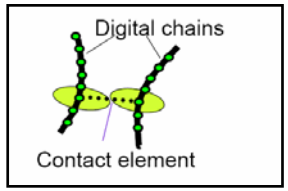
The resulting analysis tool could provide the *critical link* between <u>textile manufacturing</u> and <u>ballistic performance prediction</u> for textile protection systems.

Sub-yarn Fabric Modeling

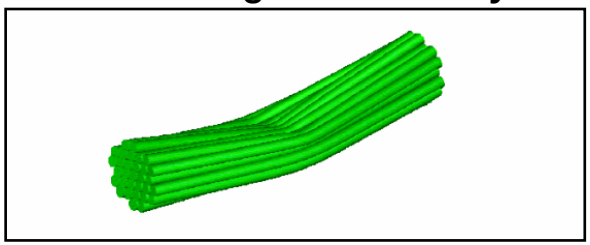
- **Textile manufacturing simulation taking computing time**

'Digital Elements (chains)' = Filaments

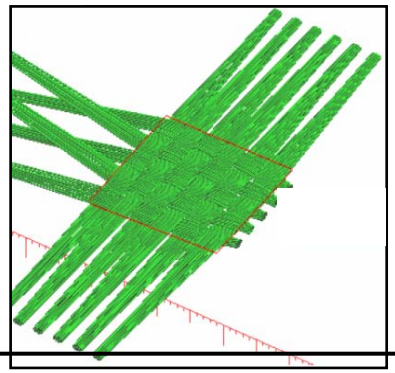


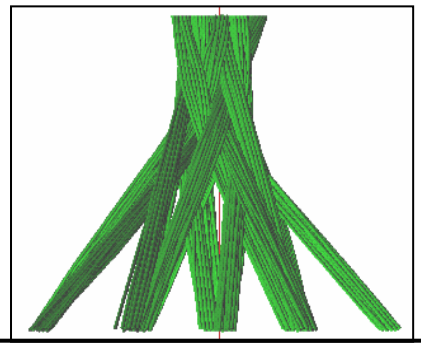


Assemble digital chains = yarn

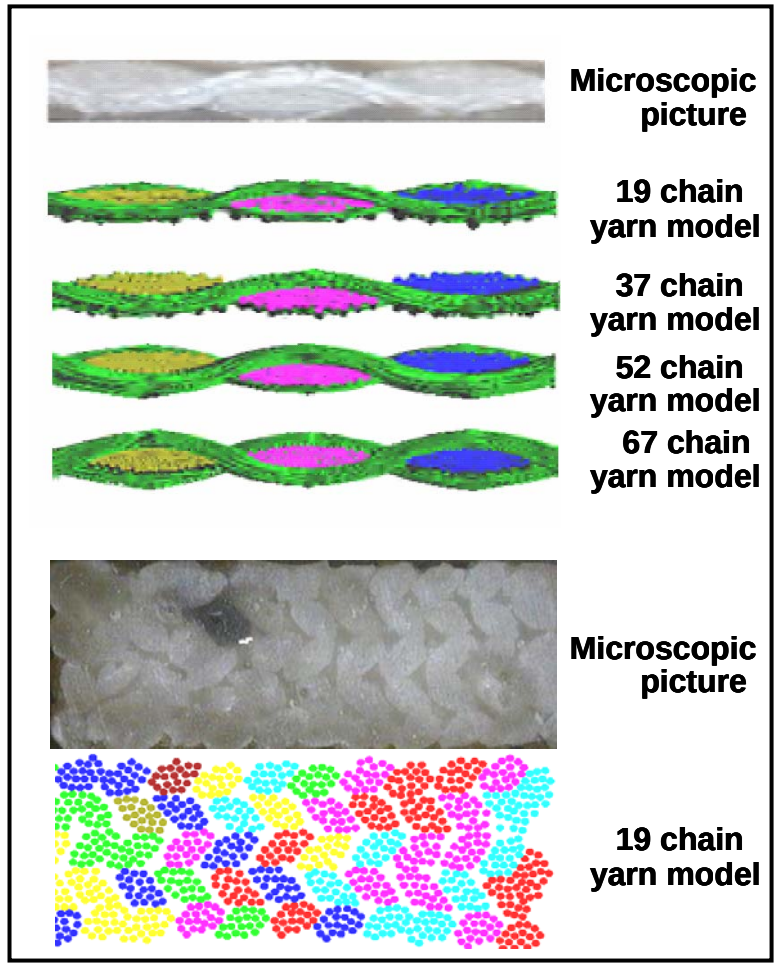


Yarns utilized in textile manufacturing simulation





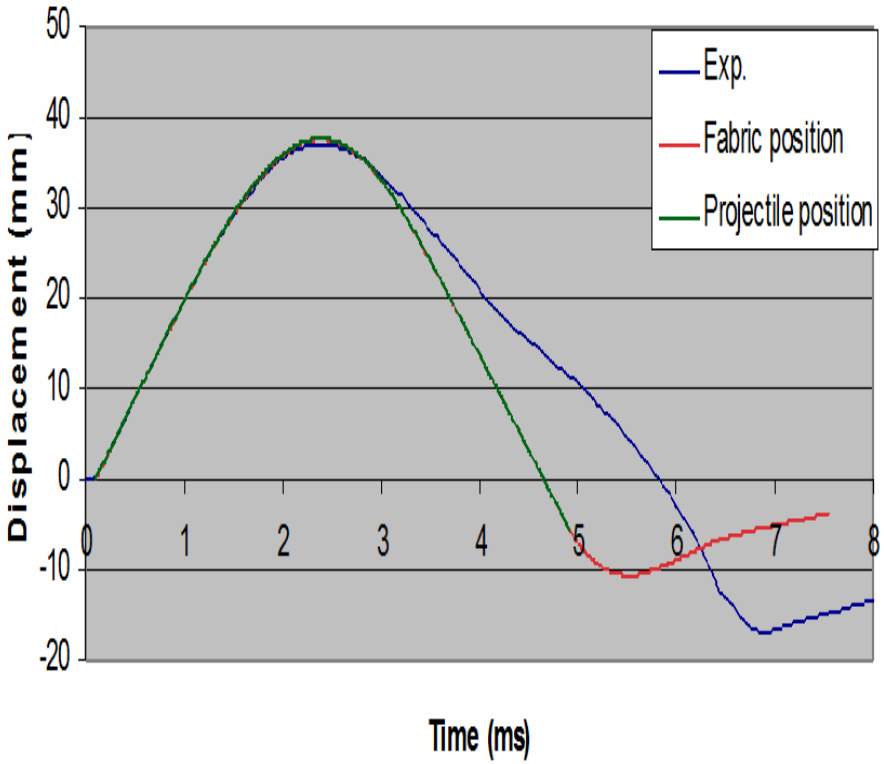
- **Develop explicit formulation for manufacturing process**



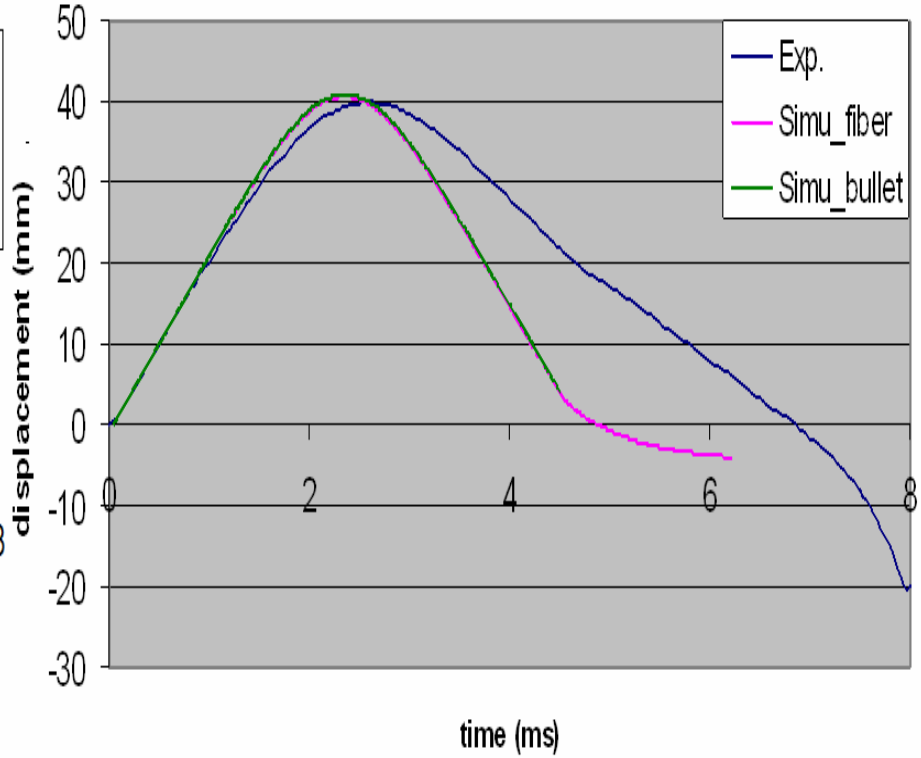
Results reported out at the Army Science Conference, Fiber Society Meeting and two Journal papers

Sub-yarn Level Modeling: Displacement Comparison

Circular Fixture

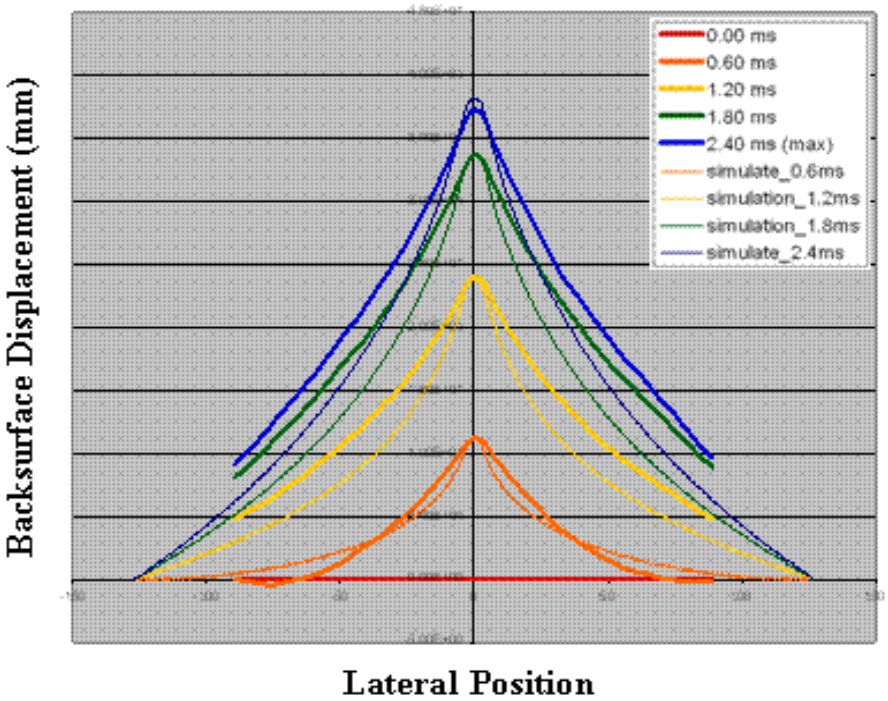


Square Fixture

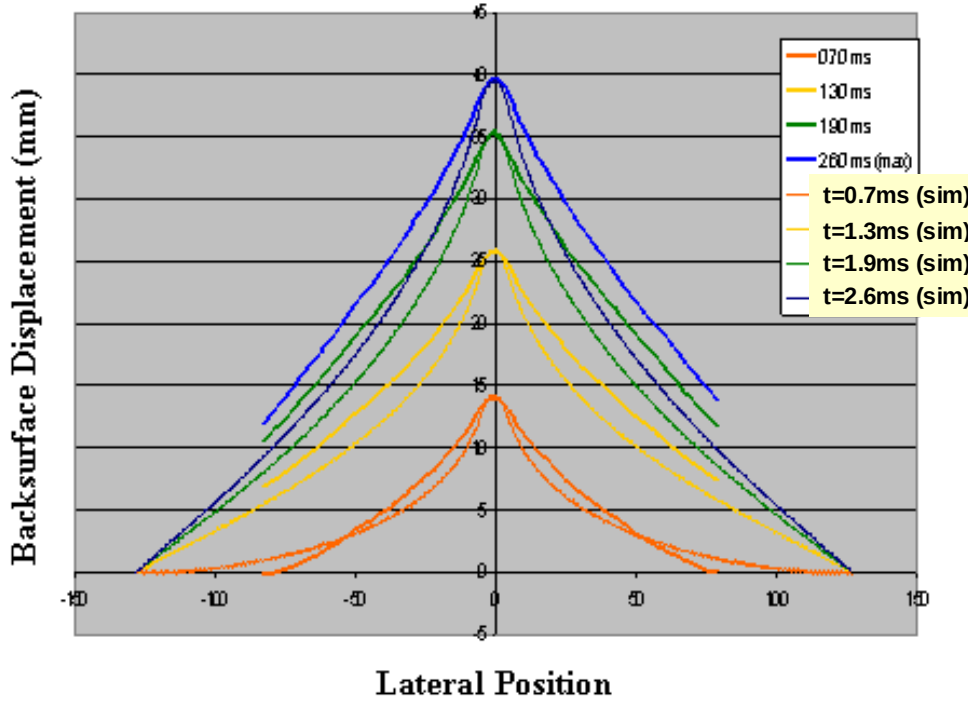


Sub-yarn Level Modeling:
Displacement Profile Correlation

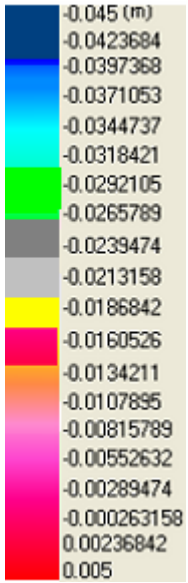
Circular Fixture

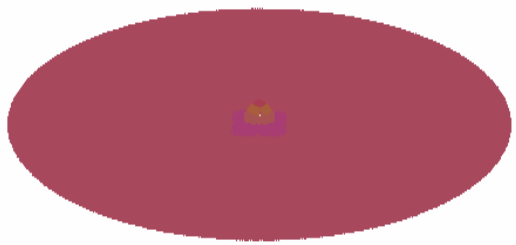


Square Fixture



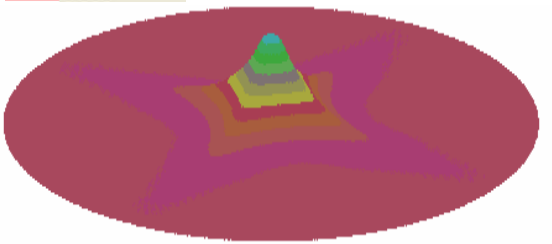
Fabric deflection (KSU, Num.)



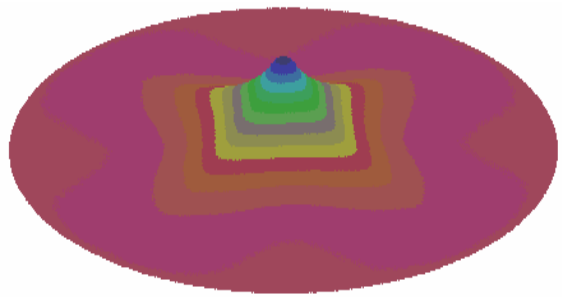


t=0.407 ms

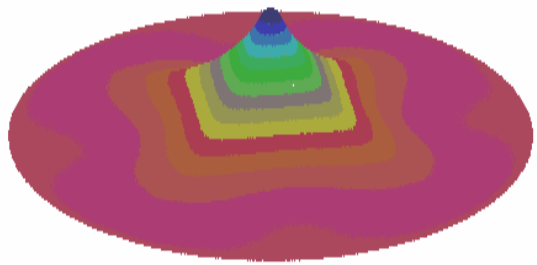
t=0.934 ms



t=0.135 ms



t=0.187ms



0.208 ms

Conclusions

- **Two computational approaches have been developed to simulate ballistic impact and penetration of the textile fabric**
  - **Yarn level model**
  - **Digital Element model with almost filament level resolution**
- **Limited validation of the simulation with experiments has been conducted**
  - **Current results indicate good agreement**
  - **Further validation is being performed.**
- **Additional failure mode (filament shearing) and statistical fiber strengths are being incorporated in both models for ballistic modeling**
- **The developed simulation capabilities would allow a material-by-design approach to textile protection systems**
  - **Yarn-level model provides computational efficiency on modeling and designing multi-layer fabric protection**
  - **Sub-yarn-level model by using digital element approach provides**
    - **Capability of linking the manufacture of a textile to its ballistic performance**
    - **Quantifying the effect of filament-level parameters such as inter-yarn friction, yarn twisting and pre-yarn tension on the textile fabric ballistic protection efficiency**
- **When matured and validated, these fabric modeling technologies will allow rapid screening of advanced, novel, hybridized textile systems incorporating differing textile architectures and will enhance our capability for adapting to new threats and integrating new materials as they become available.**