# MULTI SCALE MODELING OF THE IMPACT OF TEXTILE COMPOSITES


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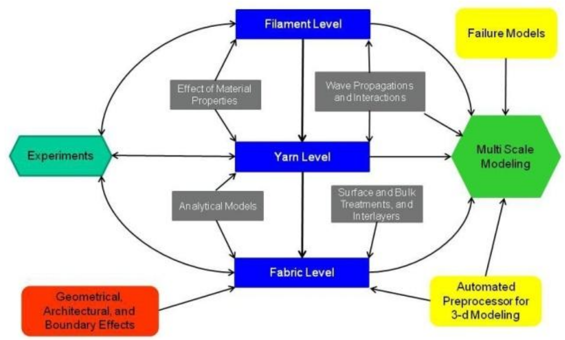
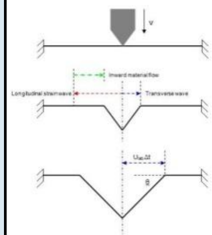
## OBJECTIVE

- Develop finite element (FE) models to accurately simulate the impact of textile composite structures
- Formulate analytical models of yarn and fabric impact
- Understand the complex interactions that occur from the filament to the fabric level
- Isolate and rank energy dissipation mechanisms during fabric impact
- Develop advanced material and failure models for the orthotropic textile composites
- Create multi scale fabric models to reduce computational expense
- Create automated preprocessors with an easy to use graphical user interface that can rapidly create FE models of textile composites

## METHODOLOGY




## ANALYTICAL MODEL - YARN TRANSVERSE IMPACT



$$c=\sqrt{\frac{E(1-\upsilon)}{(1+\upsilon)(1-2\upsilon)\rho}} \qquad W=c.\varepsilon$$

$$U_{lag}=c\sqrt{\frac{SJF.\varepsilon}{1+SJF.\varepsilon}} \qquad SJF=NR+1$$

$$SE_{yarn}=\int_0^L E(\dot{\varepsilon})\varepsilon^2 A dx$$

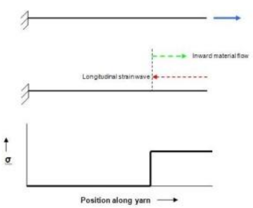
$$KE_{yarn}^{smeared}=\frac{1}{2}m_{yarn\_inst}v_{(n)}^2=2\int_0^{L^{(n)}}\frac{1}{2}\rho A dx\left(\frac{v^{(n)}x}{L^{(n)}}\right)^2$$

$$KE_{yarn}^{interpolated}=\frac{1}{4}\rho A L^{(n)}\left(v^{(n)}+v^{(n-1)}\right)^2 \qquad \Delta t\le\alpha\frac{\left(m_{projectile}-m_{yarn}\right)c}{EA}\sqrt{\frac{1+\varepsilon_{fail}}{\varepsilon_{fail}}}$$

$$v=\sqrt{(1+SJF.\varepsilon)^2U_{lag}^2-\left[(1+SJF.\varepsilon)U_{lag}-W\right]^2}$$

$$v^{(n)}=v^{(n-1)}\left(\frac{1-\chi}{1+\chi}\right) \quad \text{where} \quad \chi=\frac{E.A.\Delta t}{c\left(m_{projectile}-m_{yarn\_inst}\right)}\sqrt{\frac{SJF.\varepsilon}{1+SJF.\varepsilon}}$$

## ANALYTICAL MODEL - YARN TENSILE TESTING




$$\frac{\partial^2u}{\partial t^2}=c^2\frac{\partial^2u}{\partial x^2}$$

$$u(t)=at^1+bt^2+ct^3+...$$

$$\varepsilon=\frac{\partial u}{\partial x} \qquad \varepsilon_y=-\upsilon_{xy}\varepsilon_x$$

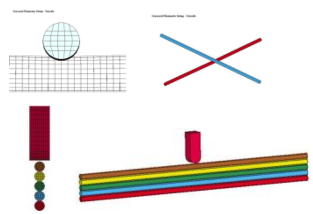
$$\sigma_x=\frac{E}{c}\frac{\partial u}{\partial t}$$

$$SE_{yarn}=\frac{1}{2}\int_0^L E(\dot{\varepsilon})\varepsilon^2 A dx \qquad F=\frac{2EA}{c}\frac{\partial u}{\partial t}$$

$$KE_{yarn}=\frac{1}{2}mv^2=\frac{1}{2}(\rho Al)(c\varepsilon)^2$$

## FILAMENT INTERACTIONS

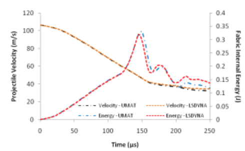
- Study wave propagations and interactions between filaments in various configurations: Parallel, Stacked, and Crossed
- Parametric studies on effect of material properties and interfacial treatments on interactions



## USER DEFINED MATERIAL AND FAILURE MODEL

*Maximum Strain Energy Density* failure criterion

- Reduces effects of numerical noise that may instigate premature failure
- Applicable to all finite element types including fully integrated 1-d to 3-d
- Allows the choice of which stress components to include in the failure
- Provides a platform to develop advanced material and failure models




## USER DEFINED MATERIAL AND FAILURE MODEL

(1) Calculate the strain and stress increments

$$d\varepsilon_i=d\dot{\varepsilon}_i\times dt$$

$$d\sigma_{ij}=C_{ij}d\varepsilon_{ij}$$

(2) Update the stress

$$\sigma_i^{(n)}=\sigma_i^{(n-1)}+d\sigma_i^{(n)}$$

(3) Calculate the strain energy density

$$SE^{(n)}=SE^{(n-1)}+0.5\left(\sigma^{(n-1)}+\sigma^{(n)}\right)d\varepsilon$$

(4) Failure condition

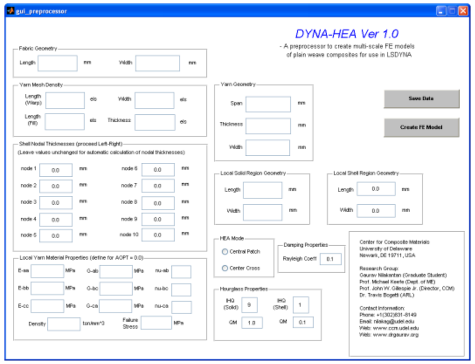
$$SE_{element}>SE_{fail}$$

# MULTI SCALE MODELING OF THE IMPACT OF TEXTILE COMPOSITES

**(Continued)**

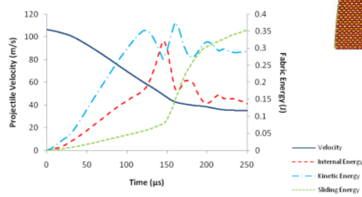
## AUTOMATED FINITE ELEMENT PREPROCESSORS

Rapidly create 3-d finite element models of plain weave composite structures for analysis in LS-DYNA®

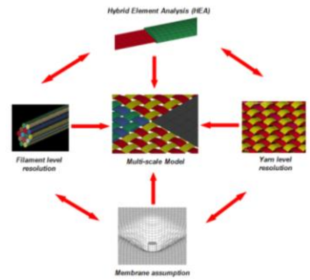


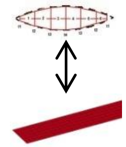

DYNA-HEA

## IMPACT TESTING OF FABRICS – BASELINE MODELS




## IMPACT TESTING OF FABRICS – MULTI SCALE MODELS

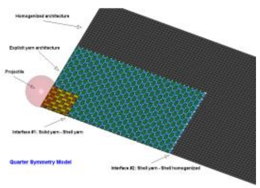


New method of modeling yarns with shell elements

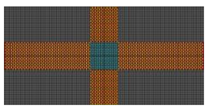
- Massive savings in computational expense
- Enables simulation of fabric targets with multiple layers and very large dimensions
- Degree of resolution is maximum at the impact zone and decreases away from it
- Includes yarns modeled with shell elements that utilize non-uniform nodal thicknesses

## MULTI SCALE MODELS – HYBRID ELEMENT ANALYSIS

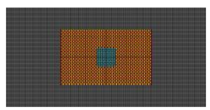



*Hybrid Element Analysis (HEA)* is defined as ‘*the finite element analysis of a structure by combining different finite element formulations at both a single and multiple scales of modeling*’

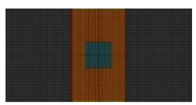
## HEA MODELS



Center Cross



Central Patch



Center Strip

Estimation of global region properties (E, ρ, t) requires the matching of (1) areal density (2) total impedance across interfaces, and (3) unaffected longitudinal strain wave and transverse displacement wave propagation

## FUTURE WORK

- Develop analytical models for fabric impact and derive parameters to assess fabric performance
- Incorporate strain rate and length scale effects with a continuum damage type failure model into the user defined material model
- Model fabric targets with multiple layers
- Study the effect of interfacial treatments on energy dissipation of flexible fabric targets
- Optimize the HEA multi scale model for further computational savings
- Modeling of yarns with a filament level architecture

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