New and creative engineering approaches developed during NESC technical activities.

Computational Modeling of Failure at the Fabric Weave Level in Reentry Parachute Energy Modulators

Energy modulators (EM) are textile mechanical devices designed to dissipate snatch loads that occur when parachutes are deployed. Although critical for mitigating shock loads, recent flight testing has shown increasing variability in EM behavior, raising concerns about their performance predictability and potential failure under dynamic loading conditions. In response, a novel approach was implemented to create a computational model of an EM at the fabric weave level using the simulation software, LS-DYNA. This work was organized into two primary objectives: (1) development of a per-unit stitch model capturing the geometry and material behavior of the EM stitching pattern, and (2) implementation of a Python script to duplicate the unit model along the full length of an EM ear, simplifying the process of generating complex, patterned geometries in LS-DYNA.

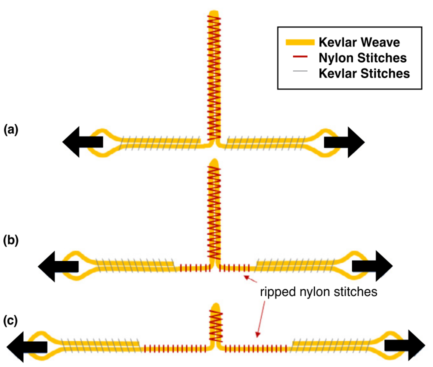
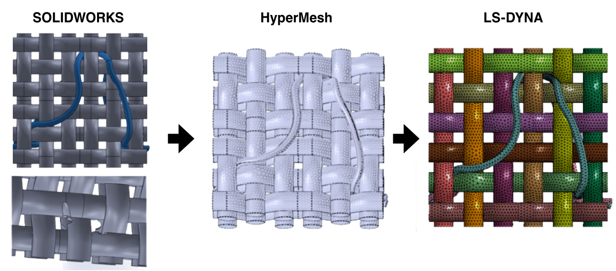


Figure 1: Depiction of EM extension during stroking from a tensile force applied at the blue arrows with (a) an unextended EM, (b) a partially extended EM, and (c) a fully extended EM

EMs typically consist of a long strip of structural Kevlar webbing that is folded and stitched together with a nylon zigzag stitching pattern to form an EM "ear." As an EM is pulled above a threshold load during deployment, the nylon stitching rips, unfolding the EM and dissipating shock forces. This process is illustrated in Figure 1, exemplifying stages of EM extension during stroking. In nominal cases, the EM cleanly tears with little damage to the Kevlar webbing. However, anomalous cases have been observed where the nylon stitches along the ear are skipped during loading, i.e., when a row of stitches do not tear in sequence. This results in failure of the surrounding Kevlar webbing, referred to as EM shredding. The inherent unpredictability of the fabric behavior and the high variability of flight loading conditions make a root cause challenging to identify through mechanical testing.

In this study, development of a computational model of an EM in LS-DYNA was used to gain deeper insight into the cause of EM shredding. While similar studies of fabric webbing have modeled fabrics at a global level, this approach represents each thread of the Kevlar weave and nylon stitching as individually modeled 3D solid elements. Modeling each thread individually within the weave is essential not only for analyzing the failure mechanisms of the nylon stitching as it rips, but also for understanding the Kevlar weave failure during the EM shredding events.

The first phase of this work focused on modeling individual Kevlar and nylon threads within a representative stitch geometry. A 3D model of the Kevlar weave was first generated using TexGen, an open-source software developed at the University of Nottingham. Using computer-aided design (CAD) software, nylon stitching passing through two layers of the Kevlar fabric weave was added. The nylon stitching pattern consisted of a bobbin thread and a needle thread that looped through the top and bottom layers, respectively, of the Kevlar weave pattern and twisted together at the end of every stitch between the two layers. The unit model was meshed in Hypermesh with 3D tetrahedral solid elements.



In LS-DYNA, the material properties, contact, failure conditions, and boundary conditions were defined to assess the dynamic response of a stitch during tensile loading. Material behavior for both fabric types was defined using *MAT_ELASTIC (*MAT_001), and two-way, surface-to-surface contact with erosion was implemented to capture progressive failure of the Kevlar weave and nylon threads. Boundary conditions were applied to replicate in-flight tensile loading scenarios. Additionally, several case studies were conducted to reduce computation time, including manual mass scaling, characteristic length analysis, and mesh quality optimization.

Preliminary results from the EM per-unit model validated the use of solid elements to capture EM behavior, particularly the interaction between Kevlar and nylon threads. To streamline the construction of full-length EM models, the second phase of this work focused on developing a Python script to replicate the per-unit LS-DYNA model along the length of an EM ear. This eliminated the need for large CAD assemblies by generating the full model directly from duplicating the unit model. This model is applicable to both solid and shell 2D and 3D elements. Overall, these results will not only aid in identifying the root cause of EM shredding but also support the evaluation of new EM design variations. This modeling approach has broader implications for other work involving fabrics, enabling more accurate simulations and efficient design workflows in aerospace textile applications. ●

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