Practical Tips for Setting Up an LS-DYNA MAT_213 Analysis

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Where We Were in 2012

- Eli Manning leads the New York Giants to defeat the New England Patriots in Super Bowl XLVI.
- *The Avengers* unite to stop Loki from unleashing an alien invasion and conquering Earth.
- Social media giant Facebook goes public at $38 a share ($580+ now) and acquires the startup company Instagram.
- The satirical K-pop song *Gangnam Style* becomes the first YouTube video to reach 1 billion views.
- The NASA Curiosity rover successfully lands on Mars using the “sky crane” descent system.
- **LS-DYNA’s composite modeling capabilities were limited.**

Where We Were in 2012

- **MAT_022** - Chang-Chang linear elastic with no rate sensitivity
- **MAT_054** - Chang-Chang/Tsai-Wu with no rate sensitivity; Matzenmiller in compression
- **MAT_058** - Matzenmiller with no rate sensitivity
- **MAT_158** - Extension of MAT_058; rate sensitivity added
- **MAT_161/MAT_162** - Hashin and Matzenmiller-based damage evolution with rate sensitivity

Available composite models:
- Based on unidirectional composite theory
- Rely on point-wise properties
- Do not holistically treat material inelasticity and damage

"Create a general material model for PMC composites which can predict impact results from mechanical properties, without relying on post impact correlation" – 2012 AWG meeting

MAT_213 Development Timeline

- 2012 – Development starts (FAA/NASA/ASU/GMU/LSTC)
- June 2016 – Appears in LS-DYNA DEV (1.0)
- 2016-2017 – First independent evaluation (NASA ACP partner)
- 2017 – Appears in LS-DYNA R10.0 (1.3.2), NASA funding ends
- 2018-2025 – Yearly updates to improve capabilities
- 2026 – Latest MAT_213 version released (1.3.8)
- September 2026 – FAA funding ending

Significant Accomplishments:

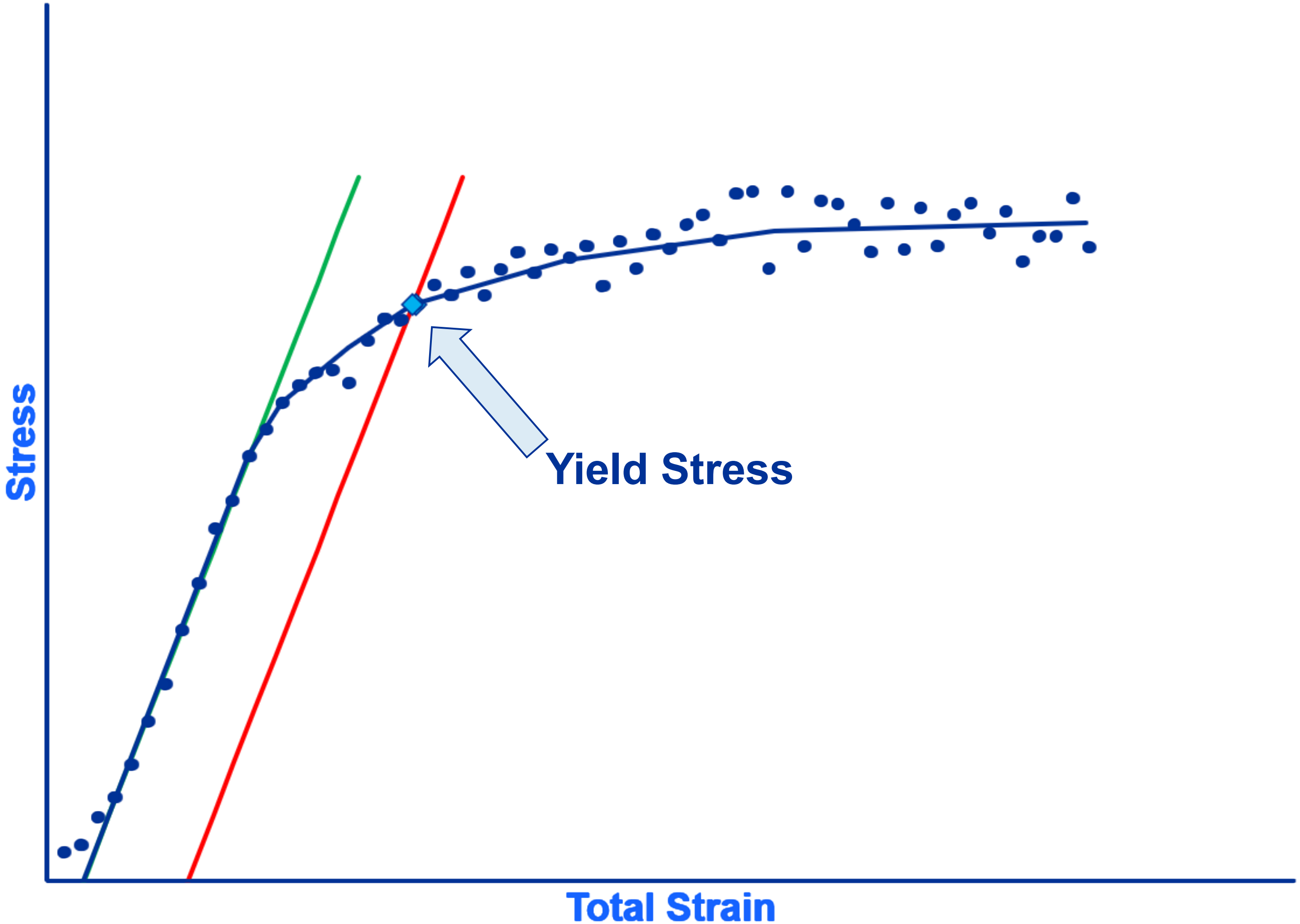
- Developed clean-sheet, generalized material model
- Improved model significantly over early releases based on feedback
- Created new composite testing methods
- Provided a comprehensive, public, composite dataset (T800/F3900)
- Successfully been applied to many composite architectures, even metals
- Many students supported and papers published

Modeled Material Systems

Model Maturity

- T800/F3900 tape (carbon, epoxy)
- AS4/PEKK tape (carbon, thermoplastic)
- IM7/PEKK tape (carbon, thermoplastic)
- IM7/8552 tape (carbon, epoxy)
- Hybrid carbon/Kevlar, epoxy plain weave
- Hexforce 282/SC-780 plain weave (carbon, epoxy)
- T700/LMPAEK tape (carbon, thermoplastic)
- IM8/PEKK tape (carbon, thermoplastic)
- 3MDCP 3D woven (hybrid carbon/phenolic tows, phenolic)

Some Basic Terminology



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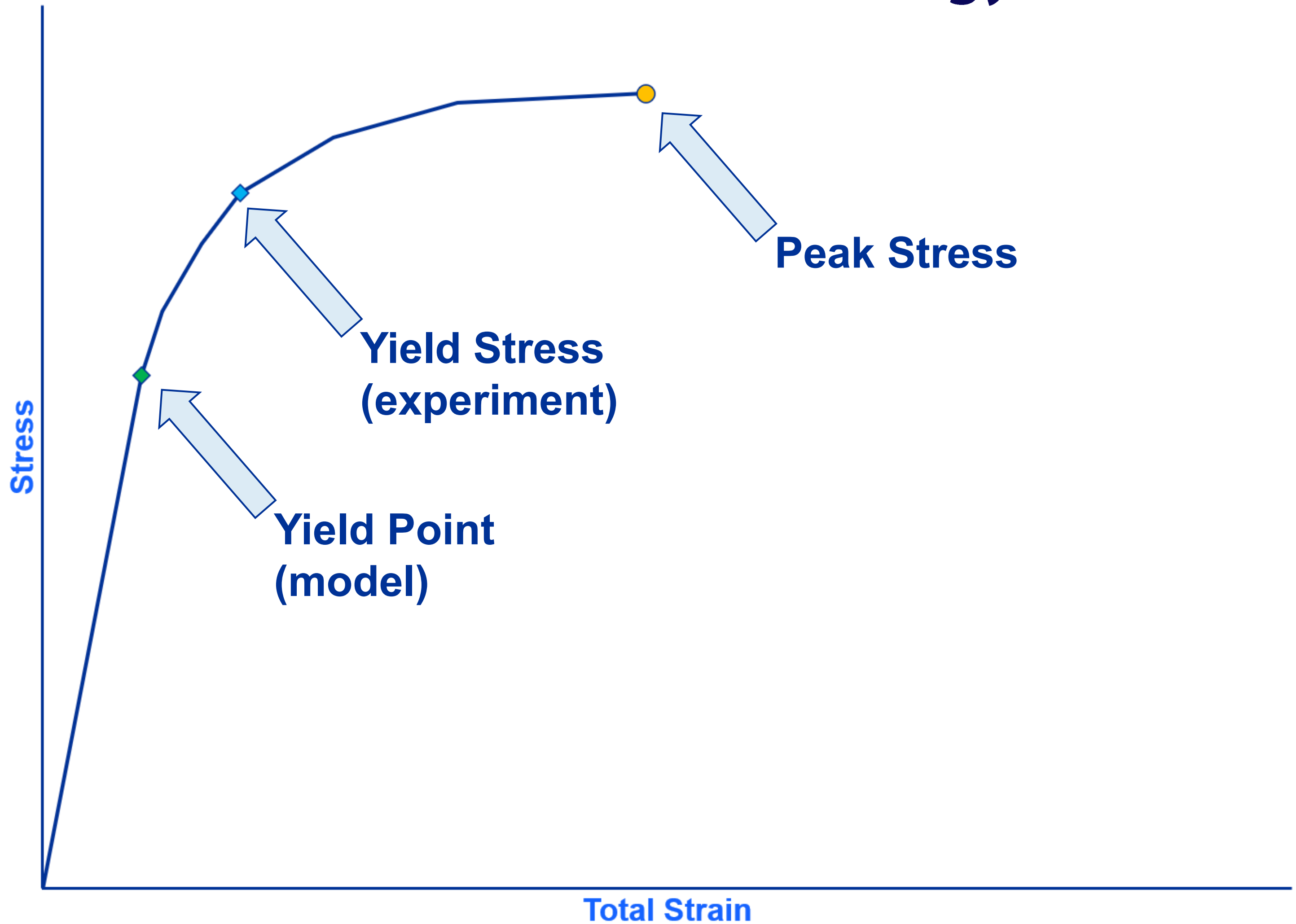

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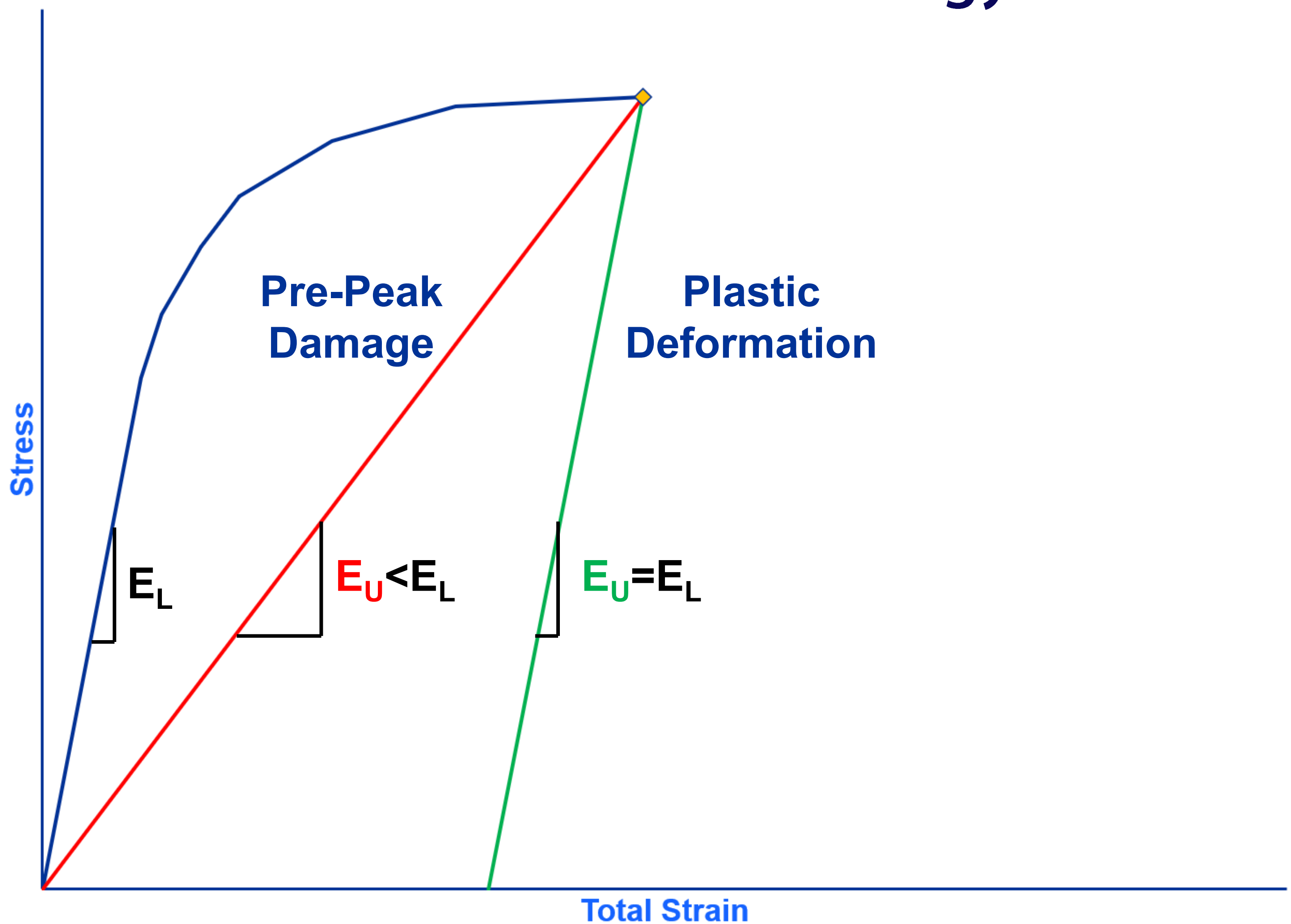

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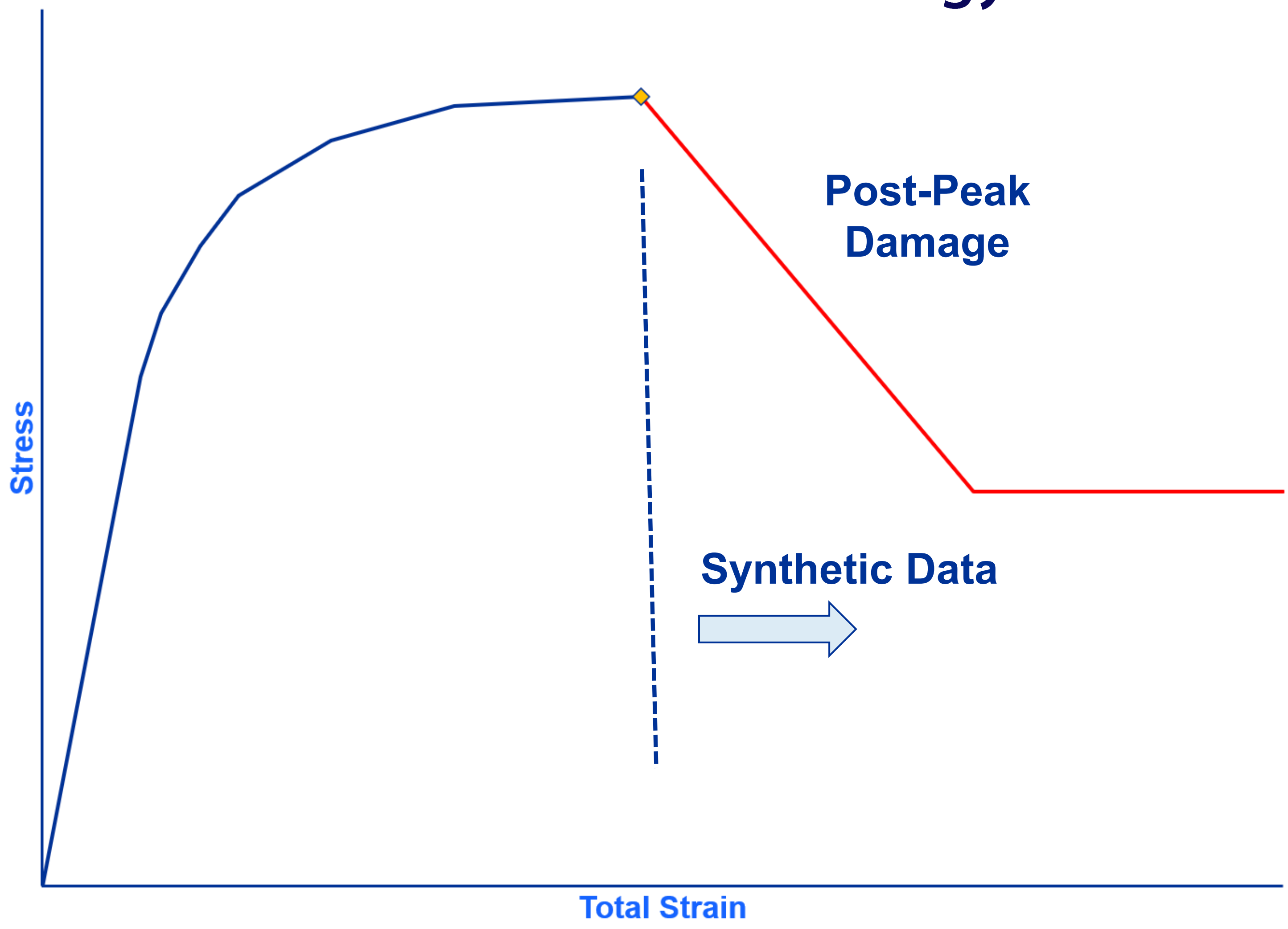

What is MAT_213?

- A highly generalized material model able to be applied to a variety of problems
  - Non-unidirectional composites (e.g., woven), anisotropic metals
  - Physics beyond impact/crush
- One of (if not) the most sophisticated material models in LS-DYNA
  - Sits at the intersection of composites theory, plasticity modeling, and damage mechanics
  - Tabulated (very few point-wise inputs)
  - Temperature and strain-rate dependence
  - Inelastic deformation model
  - Highly customizable damage and failure models
- Can take on many different forms – watch assumptions!

Good news! You do not need a PhD to create a MAT_213 model!

Helpful Resources

- AWG website (user guide, input decks):
  - https://awg.ansys.com/AWG+LS-DYNA+%2AMAT_213+Resources
- User Guide – extremely thorough document describing data collection/processing, MAT_213 inputs, examples, troubleshooting, and references
- MANY papers, theses, and dissertations available for deeper dives
- Additional Questions?
  - Dr. Daniel Cordasco (daniel.cordasco@faa.gov)
  - Dr. Robert K. Goldberg (robert.k.goldberg@nasa.gov)
  - Dr. Subramaniam (Subby) Rajan (s.rajan@asu.edu)
  - Dr. Trenton M. Ricks (trenton.m.ricks@nasa.gov)

Questions to Answer Before You Start

- What experimental data do I have (or could get)?
  - The primary question that dictates modeling approach!
- What physics are important to capture for my problem?
  - Constant strain rate vs. variable
  - Constant temperature vs. variable
  - Elastic response vs. viscoelastic vs. viscoplastic
  - Specific damage modes, uncoupled vs. coupled damage
  - Failure approach (*MAT_ADD_EROSION vs. constant failure strain vs. generic tabulated approach)
  - What if you are unsure? Start simple and gradually add new features.
- What element type(s) do I want to use?

Keywords

- Many inputs
- BUT
  - Many typical of any composites model
  - Many only used in specialized cases
  - Further reductions possible

Solution Controls

Viscoelastic Inputs

Flow Rule Coefficients

Input Curve Tables

Yield Strains

Damage Inputs

Failure Inputs

Taylor-Quinney Inputs

Temperature

```
*MAT_213
$#   Card 1
$#      MID       RO       EA       EB       EC     PRBA     PRCA     PRCB
        213 1.45E-04 2.35E+07 1.07E+06 9.66E+05   0.0168    0.027    0.439
$#   Card 2
$#      GAB      GBC      GAC     PTOL     AOPT     MACF     FILT     VEVP
   5.80E+05 3.26E+05 3.48E+05     1E-6        2        0
$#   Card 3
$#       XP       YP       ZP       A1       A2       A3
          0        0        0        0       -1        0
$#   Card 4
$#       V1       V2       V3       D1       D2       D3     BETA    TCSYM
          0        0        0        1        0        0        0        0
$#   Card 5
$#      H11      H22      H33      H12      H23      H13      H44      H55
       0.01        1        1        0   -0.776        0    4.239    15.31
$#   Card 6
$#      H66      LT1      LT2      LT3      LT4      LT5      LT6      LT7
     5.3718     1001     1002     1003     1004     1005     1006     1007
$#   Card 7
$#      LT8      LT9     LT10     LT11     LT12      YSC   DCFLAG       DC
       1008     1009     1010     1011     1012      100        1      800
$#  Card 8d.1
$#    FTYPE      FV0      FV1      FV2      FV3      FV4      FV5      FV6
          3                 2     9013     9014
$#  Card 8d.2
$#      FV7      FV8      FV9     FV10     FV11     FV12     FV13     FV14
$#   Card 9
$#   BETA11   BETA22   BETA33   BETA44   BETA55   BETA66   BETA12   BETA23
$#   Card 10
$#   BETA13       CP      TQC     TEMP    PMACC      SLM
                                    20
```

Defining the Deformation Model

- Stress-total strain curves required
  - Minimum 3 tension, 3 compression, 3 shear, 3 off-axis (optional) for single temperature, single rate
  - Elastic + inelastic + synthetic portion of curves
  - 5 required (optional off-axis) when using thin shell elements
  - Model extrapolates based on last two data points if needed
  - Assumptions/idealizations can reduce further!
    - E.g., transverse isotropy, tension/compression symmetry
- Yield strains based on deviation from linearity
  - Pay close attention to when changing input curves!
- Solution controls (PTOL, PMACC) should be varied to establish convergence
  - Often can be adjusted from defaults to result in faster analyses
- Viscoelastic-viscoplastic modeling capabilities available to use

Defining the Deformation Model

- Flow Rule Coefficients (FRCs)
  - <u>**The most difficult concept to grasp by new users**</u>
  - Choice depends on composite architecture
    - Some derivation often required (see User Guide for unidirectional composites)
  - Multiple approaches can be used to determine:
    - Using experimental data (if available), plastic Poisson ratios
    - Calibration/curve fitting with constraints
    - Assuming equivalence between elastic and plastic Poisson ratios
  - Common for results to be somewhat insensitive to shear coefficients (H44, H55, H66)
    - But choice could introduce computational instabilities
  - Simplified Material Model (no plasticity) activated by setting all coefficients to zero

Defining the Damage Model

- 84 possible damage parameters (maximum)
  - 12 uncoupled – e.g., load in 11-direction, induce 11-damage
  - 72 coupled – e.g., load in 11-direction, induce 22-damage
  - Typical analyses may use 0-5 uncoupled parameters
- Temperature and strain rate dependent parameters
- Can capture both pre-peak and post-peak softening
- Coupled to plasticity model (generally)
  - Cannot have both a zero FRC and damage for the same direction (often set FRC to a small value)
  - Yielding must occur before parameter for post-peak damage activates (a common problem with idealized models)
  - Simplified Material Model decouples, simpler to implement
- No method to automatically regularize results

Defining the Failure Model

- Governs element ***erosion*** in LS-DYNA
- Built-in or prescribed stress-degradation (most models)
- Can be disabled if *MAT_ADD_EROSION is preferred
- Generalized Tabulated Failure Criteria (GTFC)
  - Often simple to implement, good first step
- Point cloud failure criteria (PCFC)
  - More general, new as of 2025
  - Failure onset starts user-defined post-peak degradation
  - Can require more data or a methodology to predict inputs under multiaxial loading
- Traditional Tsai-Wu and Puck models available

Some Suggestions

- Read the User Guide, run examples on the AWG website.
- For a larger model, work out FEA issues with a simpler material model (e.g., MAT_002, MAT_058).
- Start with single elements to verify MAT_213 inputs, calibrate using coupon-scale simulations, predict component response
- Convert an existing composite material model, if available.
  - MAT_058 most easily done
- Use idealized curves, few points per curve.
- Get the deformation model to work first.
- Start with the Simplified Material Model (no inelasticity).
- Look for publications/presentations from the group.
  - NASA: https://sti.nasa.gov/
  - FAA: https://rosap.ntl.bts.gov/

Relieving Common Pain Points

- **Paralyzed by the amount of available inputs**
  - Start with simple models first, add new capabilities gradually
  - E.g., Simplified Material Model, symmetry assumptions
- **Difficulty in determining flow rule coefficients**
  - Leverage symmetry if possible (e.g., plain weave, H11=H22)
  - Leverage idealizations (e.g., if tension-1 is perfectly elastic, H11=0. Therefore, H12=H13=0)
  - See User Guide, publications
- **Input curves difficult to generate when using damage**
  - Start with idealized curves
  - Use same strain values for damage and stress/total strain input curves (if possible).
  - Calculate effective stress ($\sigma_{eff} = \sigma/(1-d)$) and ensure slope of effective stress/total strain curve is positive for all strains.
- **Mesh regularization not a built-in feature**
  - Use constant element sizes (both for calibration and prediction)
  - Vary any post-peak response to dissipate same energy

Questions?