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AMTAS

Advanced Materials in Transport Aircraft Structures

Certification of Discontinuous Composite Material Forms for Aircraft Structures

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University of Washington

Fall 2014 AMTAS Meeting

Edmonds Conference Center

Certification of Discontinuous Composite Material Forms for Aircraft Structures

- Motivation and Key Issues
  - Certification of DFC parts currently achieved by testing large numbers of individual parts (certification by "point design")
  - Industry goal is to transition to a certification process based on analysis supported by experimental testing

Technical Approach

- HexMC (a DFC being used on the B787) selected as a model material. For this material, perform:
  - Experimental studies of HexMC mechanical behaviors, starting with simple coupon-level specimens and progressing towards "complex" parts
  - Study effects of processing (e.g., impact of material flow during compression molding on stiffness and strength)
  - Develop stochastic ("Monte-Carlo") analysis method
  - Compare measurements with analytical-numerical predictions

People

- Current Researchers (University of Washington):
  - Prof. Mark Tuttle (PI)
  - Michael Arce, MS Student
  - Karen Harban, MS Student
- Additional Participants (University of Washington):
  - Prof. Paolo Feraboli
  - Graduate students: Marco Ciccu, Tyler Cleveland, Brian Head, Marissa Morgan, Tory Shifman, Bonnie Wade
- FAA Personnel:
  - Lynn Pham (Tech Monitor), Larry Ilcewicz, Curt Davies
- Industry Participation:
  - Boeing: Bill Avery
  - Hexcel: Bruno Boursier, David Barr, and Sanjay Sharma

Major topics of earlier papers/presentations:

- HexMC coupon tests (e.g., UNT, OHT, UNC, OHC); properties exhibit relatively high levels of scatter; HexMC is notch insensitive
  - Feraboli et al: (a) *J. Composite Materials*, Vol 42, No 19, (b) *J. Reinf. Plastics and Composites*, Vol 28, No 10, (c) *Composites Part A*, Vol 40

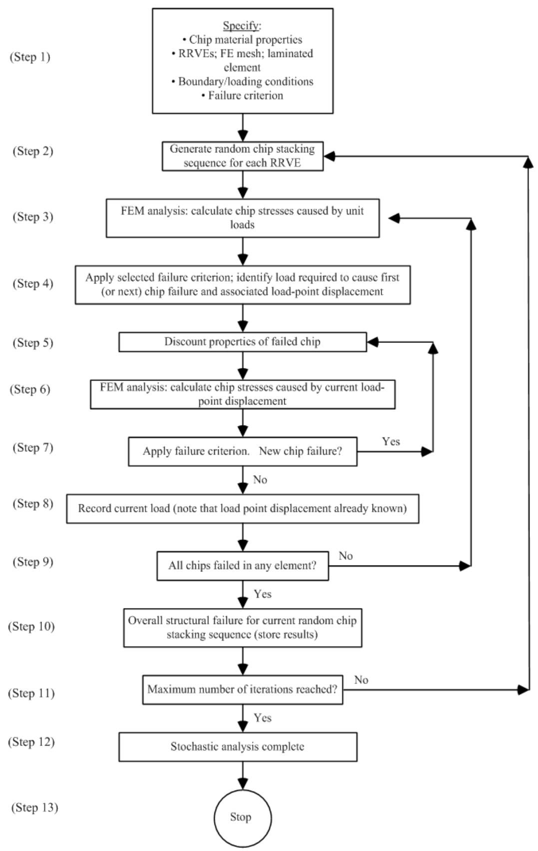
- "High-flow" and "ply-drop" panel tests: material flow causes modest chip/fiber alignment (optical microscopy) and measureable change in stiffness and strength (coupon tests)
  - Tuttle/Shifman: JAMS '09 & '10, AMTAS Fall '09 and Spr '10

- Modeling stiffness/strength via stochastic laminate analogy
  - Feraboli/Ciccu: JAMS '10 & '11, AMTAS Fall '10

Major topics of earlier papers/ presentations (cont'd):

- Measurement/prediction of elastic bending stiffness of HexMC angle beams with non-symmetric cross-sections (Multiple FEM analyses presented, based on the stochastic laminate analogy approach)
  - Tuttle/Shifman: AMTAS Fall '10, JAMS '11, Feraboli et al: JAMS '11
- B-basis and B-Max measures of HexMC modulus used during FEM analyses of HexMC beams to account for high levels of scatter in elastic properties
  - Tuttle/Head: AMTAS Fall '12 & '13
- Measurement/prediction of crippling/buckling/fracture of HexMC angle beams with symmetric cross-sections were completed (Multiple FEM analyses presented, based on the stochastic laminate analogy approach and based on deterministic B-Basis and B-Max approach):
  - Tuttle/Head/Arce: AMTAS Fall '13
- Prediction of stiffness of HexMC Intercostal (Multiple FEM analyses presented, based on the stochastic laminate analogy approach and based on deterministic B-Basis and B-Max approach):
  - Tuttle/Arce: JAMS Spring '14

Focus of this Presentation



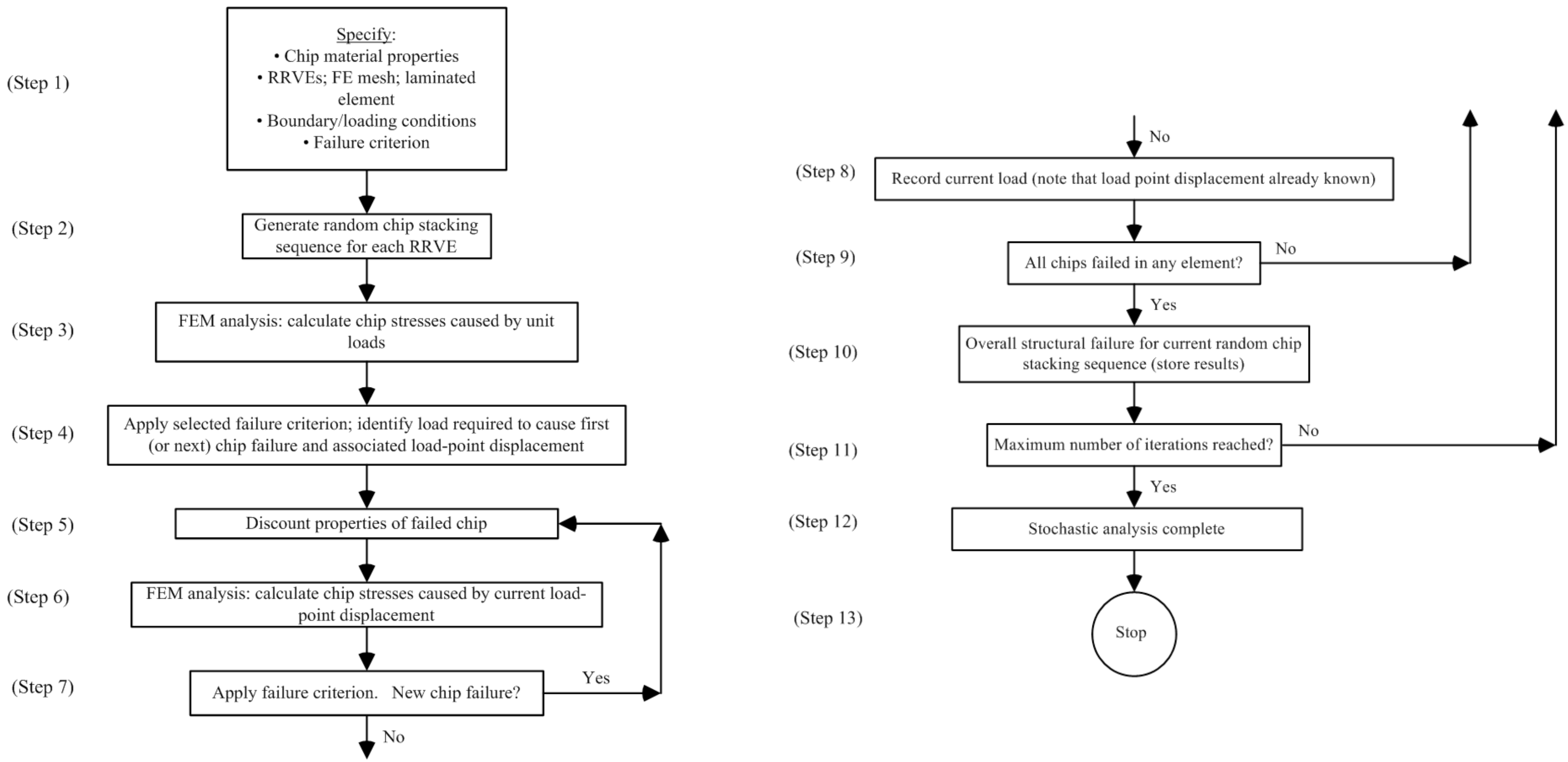
- Ply Discount Scheme and RLVE approach as applied to Intercostal

Stochastic Laminate Analogy

- The SLA approach is to consider the randomly oriented chips within the material as a multiangle composite with randomized fiber angles.

- The model is subdivided into Random Layup Volume Elements, the nominal size of which was determined using coupon test data (Head, '13).

Ply Discount Scheme Overview



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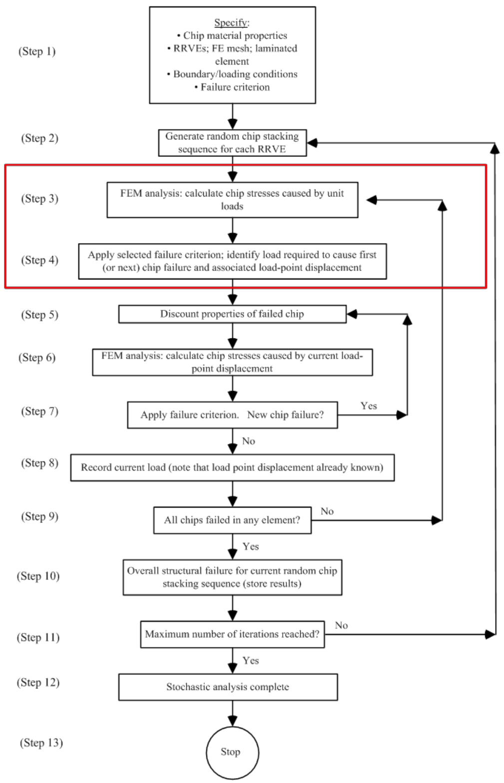
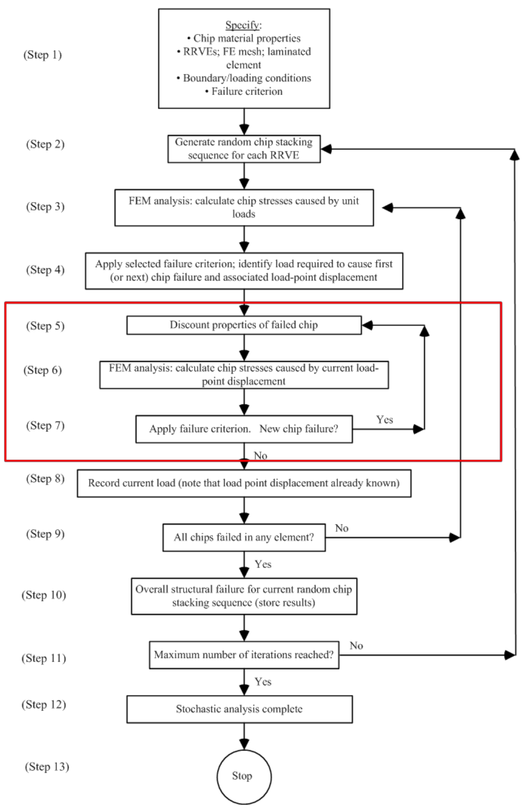
Unit Load Analysis



- A unit load is applied at the load point, simulating the loading conditions during the UW tests.
- The Tsai-Wu max failure index output vector (available in the Femap/NASTRAN software package) is used to identify the ply in which failure will occur first.
- The Tsai-Wu failure criterion is rearranged in the form of a quadratic that can be solved for the predicted load that will cause failure of the identified ply.

Enforced Displacement



- The properties of the failed ply are discounted and the displacement corresponding to the load at failure is enforced in a (new) FE analysis.
- The new analysis predicts the constraint force that is required to maintain the displacement in the (now weakened) structure.
- The Tsai-Wu criterion is used to identify any additional plies that may have failed at the current displacement; properties of the failed ply(ies) are discounted, and the process iterated.

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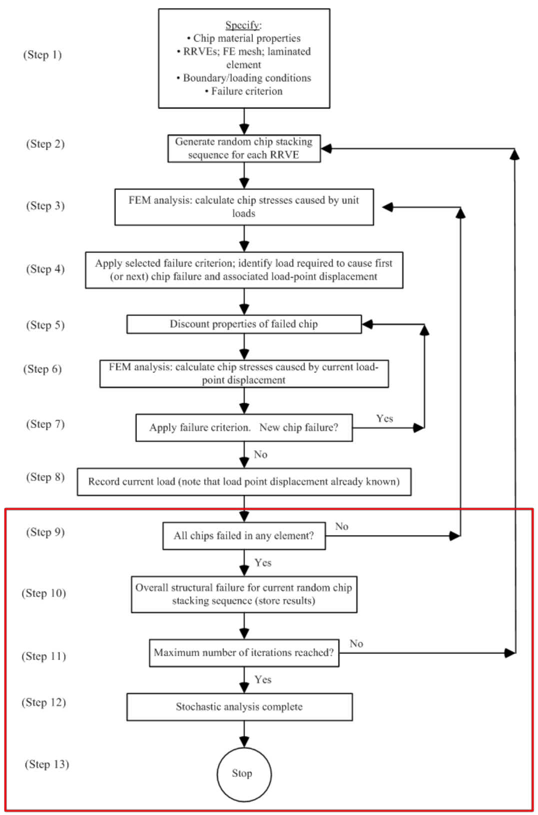
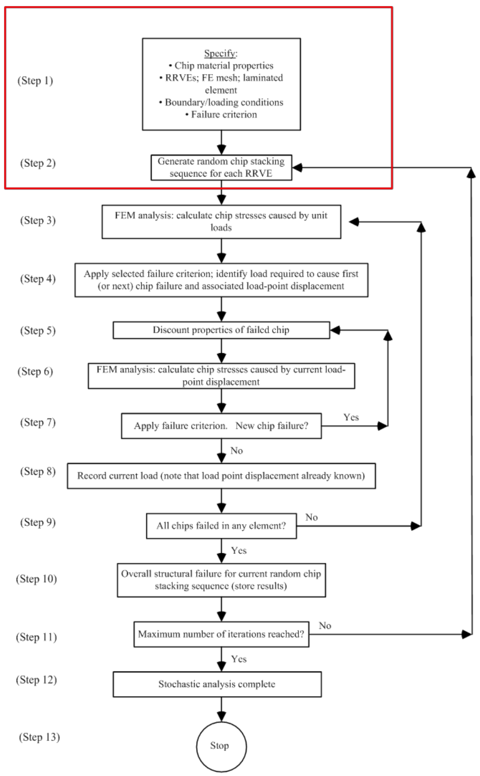
Looping and End Conditions



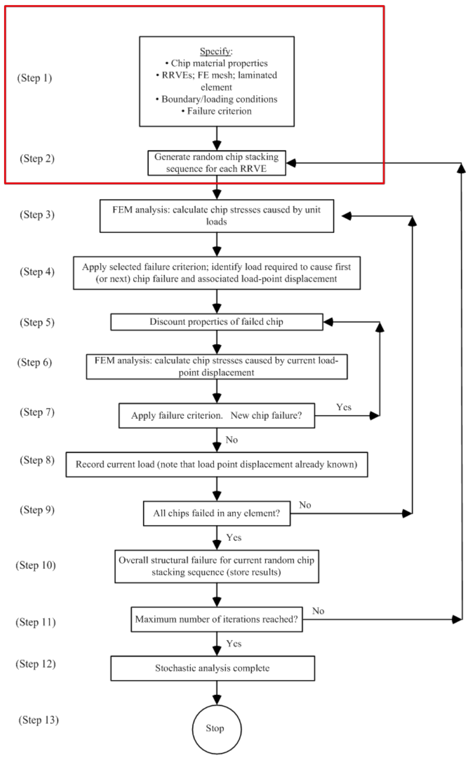
- Once no additional ply failure are predicted at the current displacement a new unit-load analysis is performed.
- Final fracture is predicted to occur when all plies within an element are predicted to have failed (as will be seen, *this may be too conservative*)
- The entire process is repeated for a “large” number of randomly-generated RLVE stacking sequences.

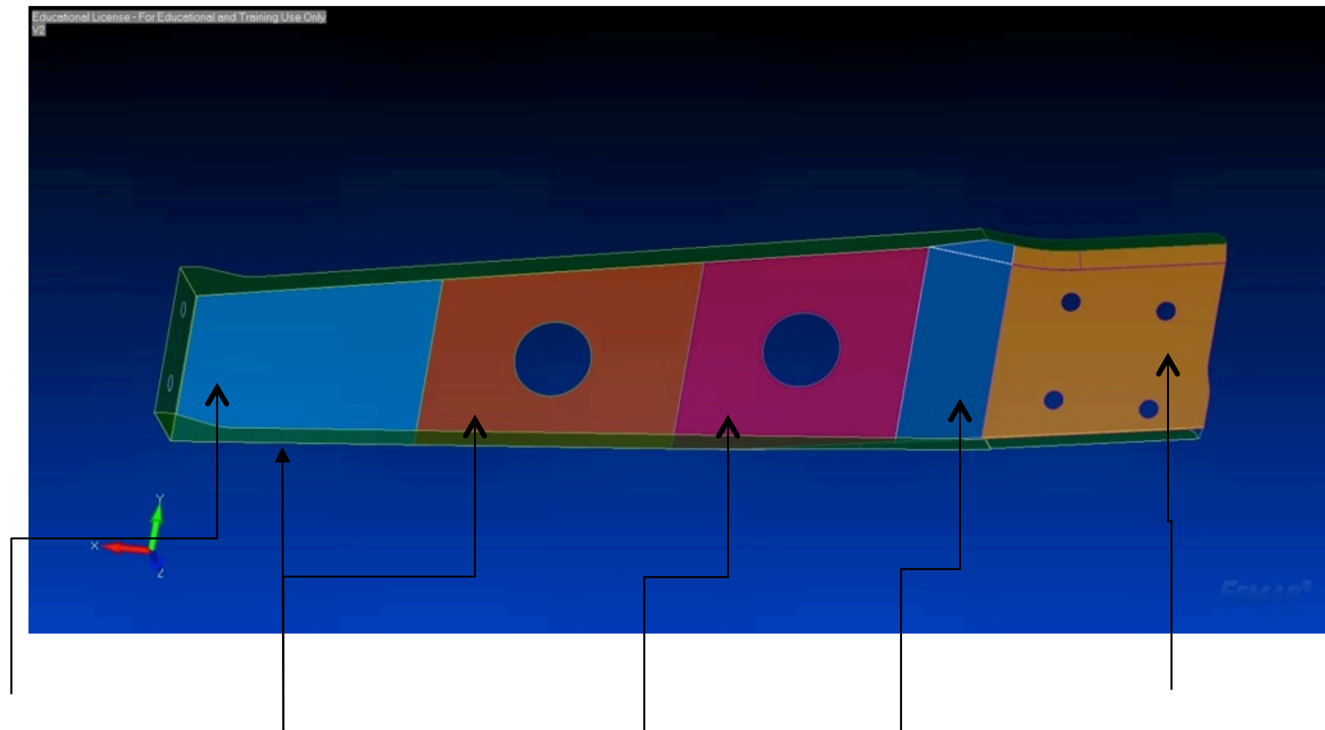
Modeling Details



- Model created with midsurfaces generated from solid model.
- Element types Nastran isoparametric CTRIA3 and CQUAD4 with pcomp card: laminate shell elements.
- Sheet solids were aggregated into one manifold solid. Due to irregular geometry, there are some gaps between midsurfaces, these are connected by rigid elements.

Thickness Variation





Thinnest Region:
0.08 inches
16 "plies"

24 "plies"

32 "plies"

48 "plies"

Thickest Region:
0.32 inches
64 "plies"

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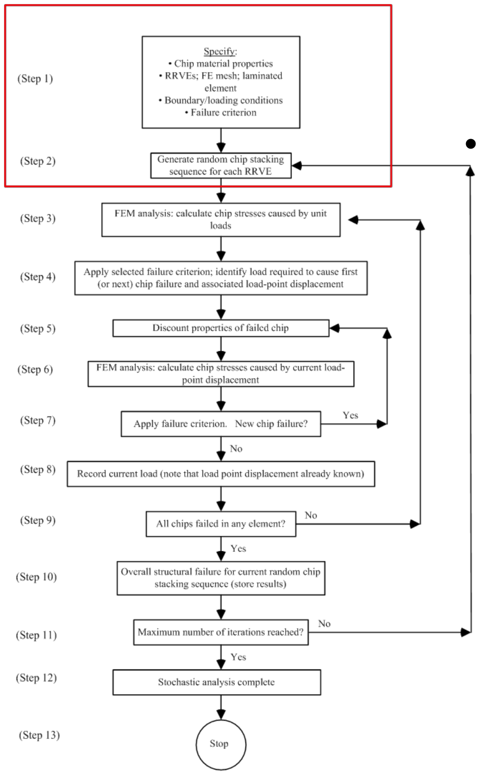
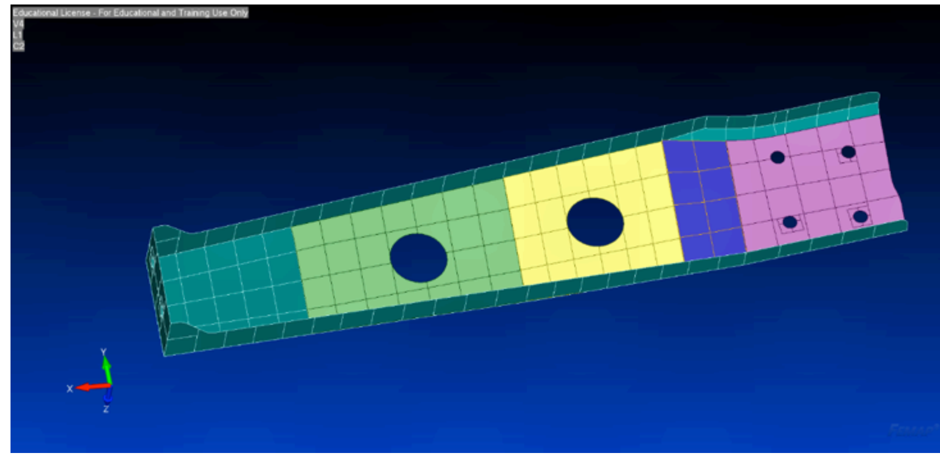
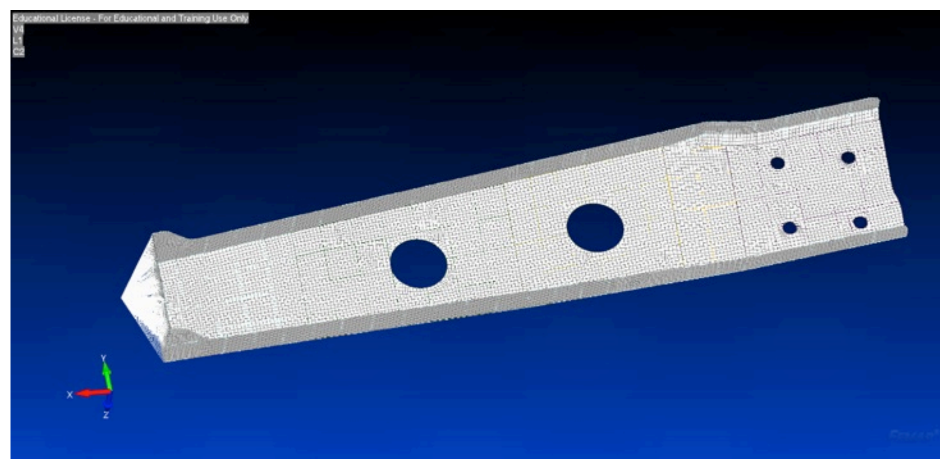
RLVEs and Mesh



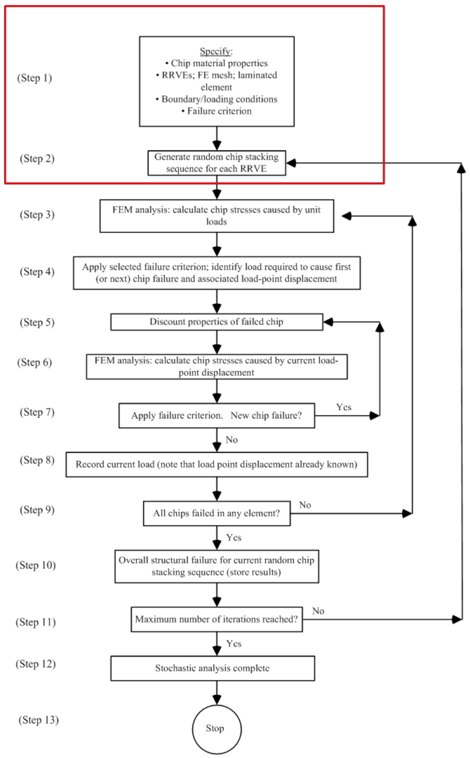
- RLVEs on Intercostal
  - Each RLVE receives a unique and random layup for every analysis

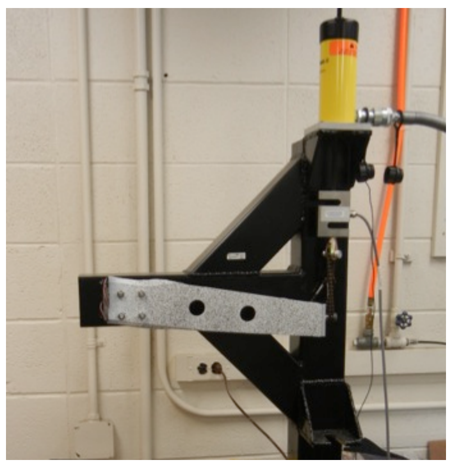


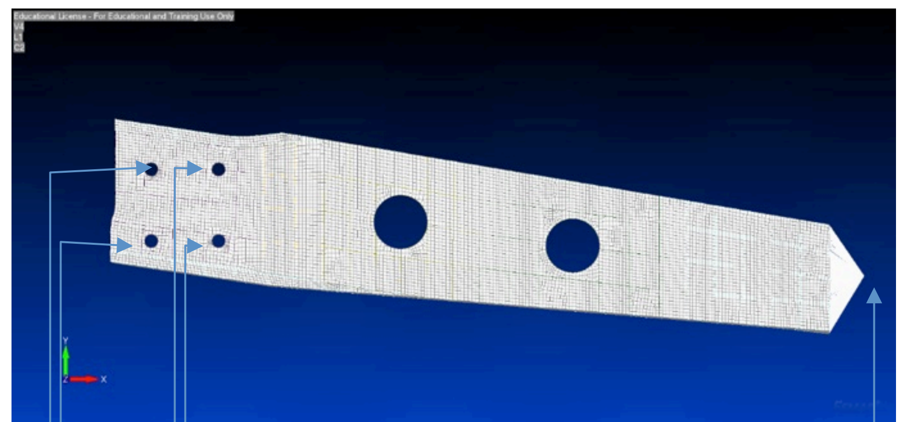
- Meshed Intercostal



UW Boundary Conditions





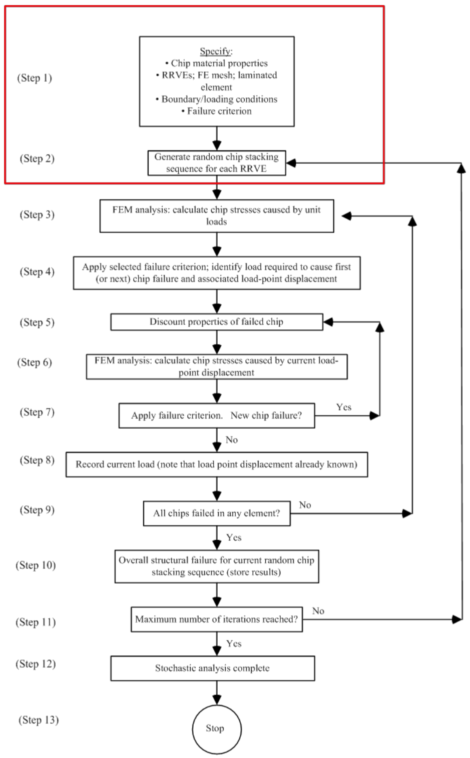


Fixed

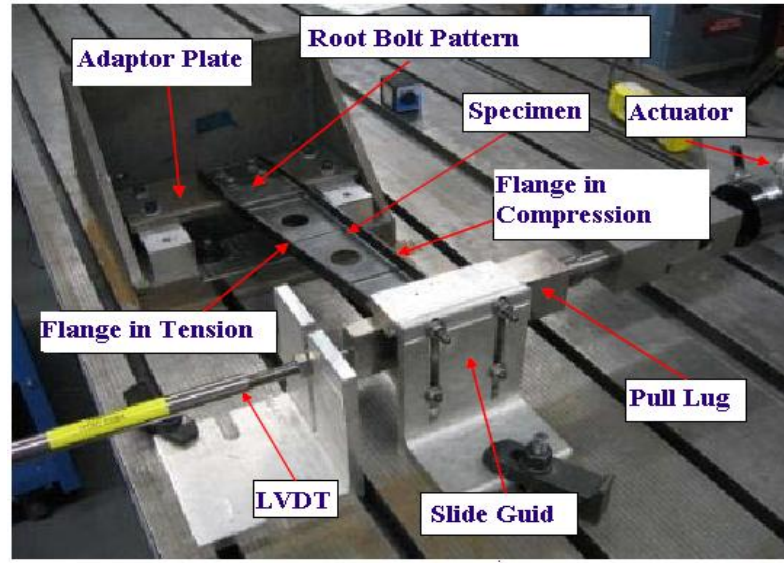
Rigid Connection to a point away from surface, allowed to rotate freely

- UW Test Rig

Hexcel Boundary Conditions

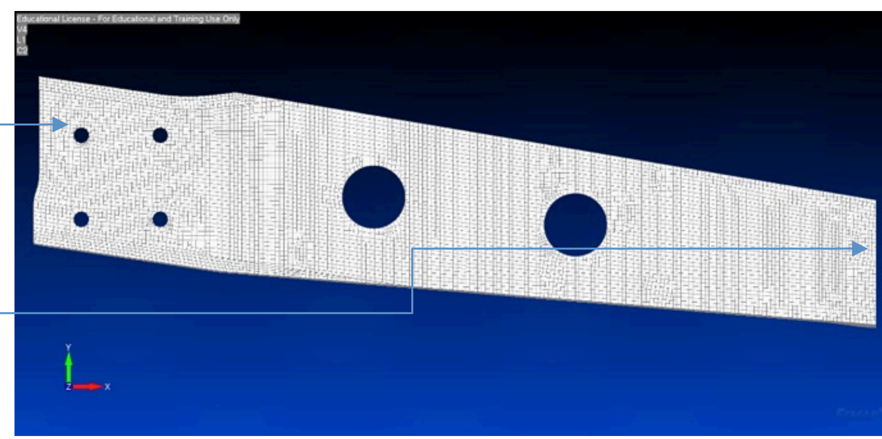


- Hexcel Test Frame



Fixed

Force per length applied to inside curves, not allowed to rotate or move out-of-plane

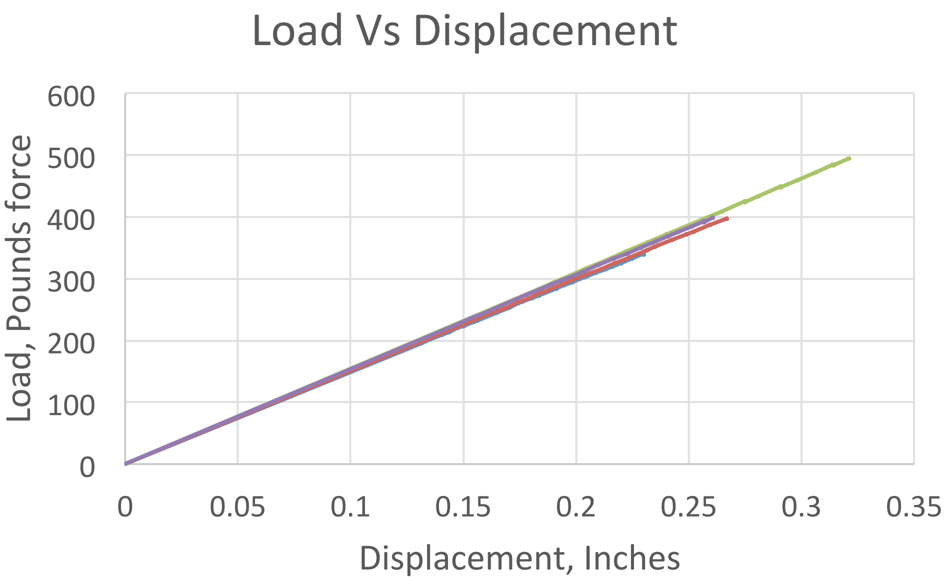


Material Properties

- AS4/8552 Properties as sourced from Hexcel
- Using AS4/8552 for a quasi-isotropic layup, CLT predicts elastic properties that are ~20% higher than published values of HexMC
- To account for this, the properties were reduced until CLT predictions matched HexMC
- Further, upon failure the elastic properties of a failed ply are reduced by factors of 0.9 for fiber dominated properties, and 0.3 for matrix dominated properties, in accordance with the standard ply discount scheme

Results: UW BCs

Analysis	Number of Failures	Load at Failure	Time
1	942	339.62	10 H, 40 M
2	765	397.41	8 H, 45 M
3	872	494.21	9 H, 10 M
4	620	397.85	7 H, 10 M



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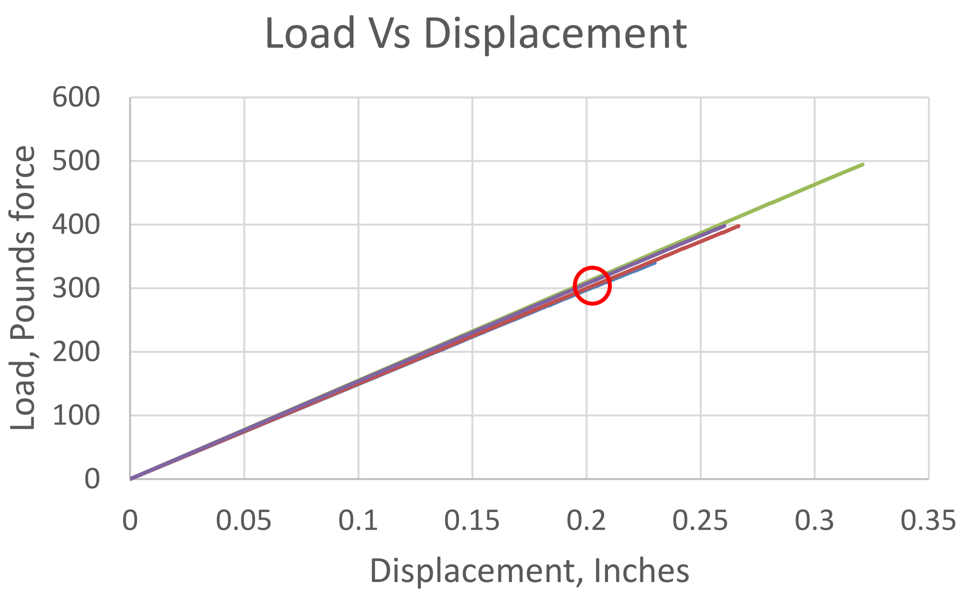
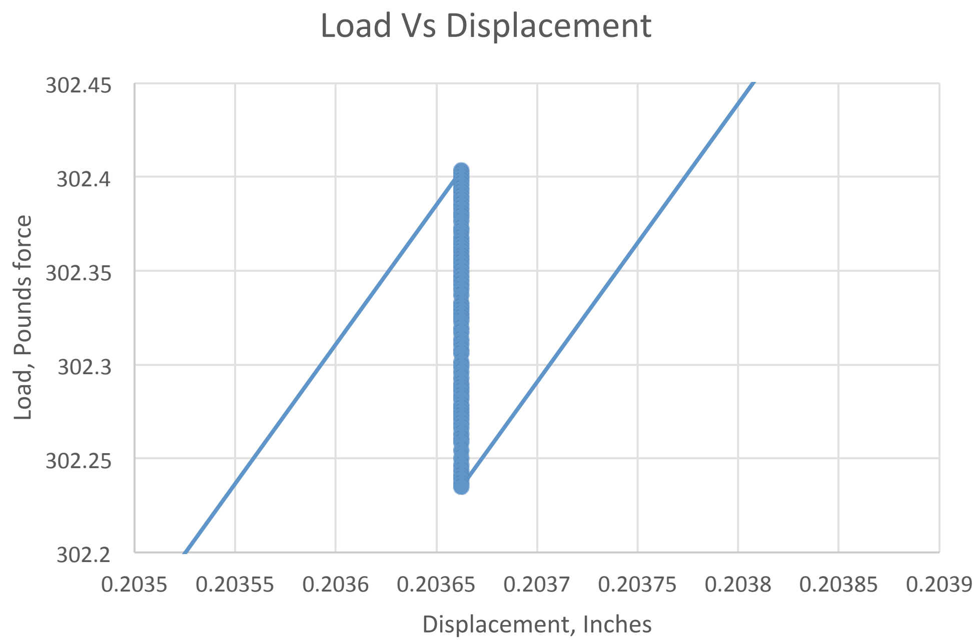
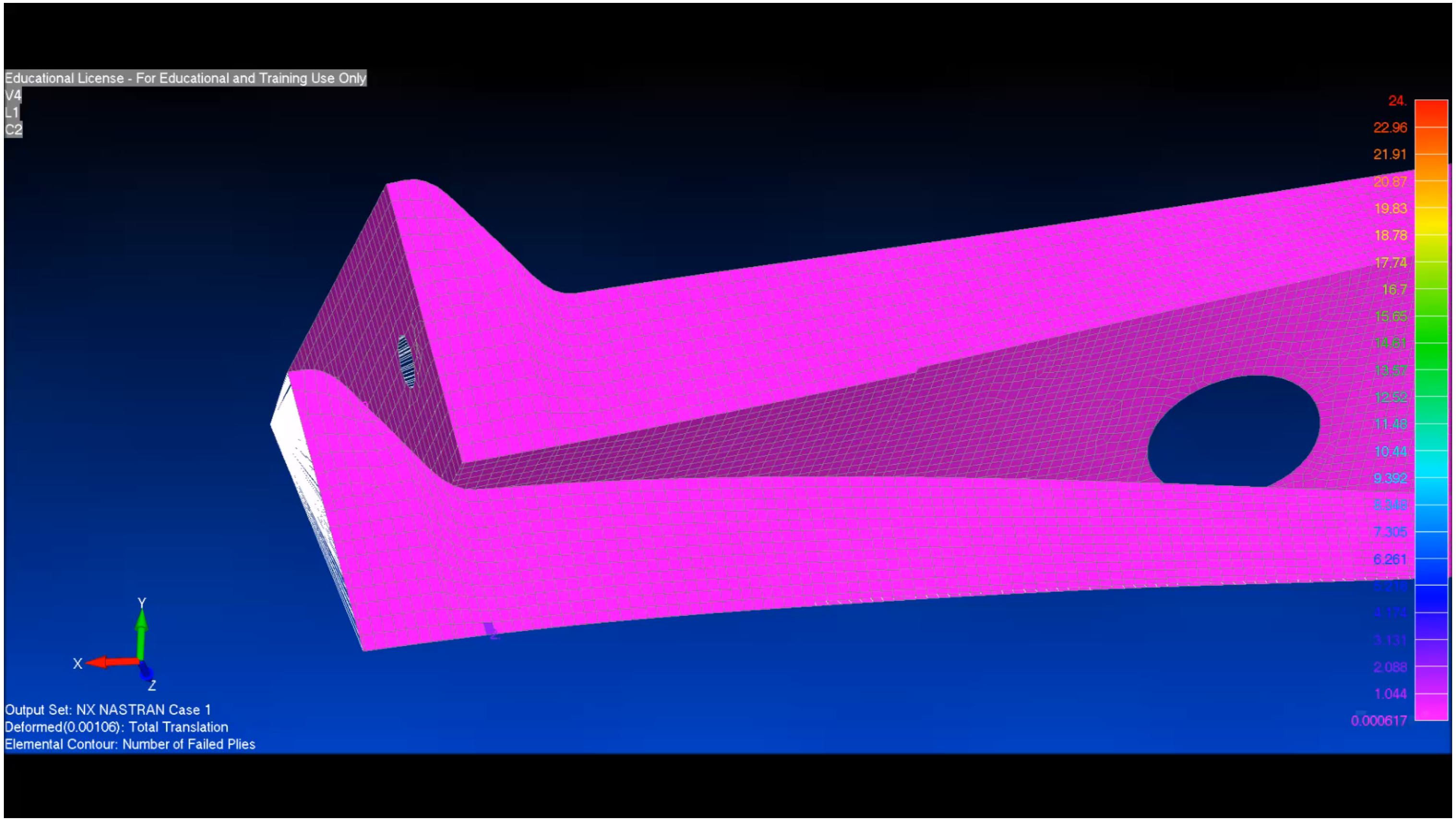


Results: UW BCs

- At normal scales the load-displacement curves appear nearly linear.
- At an expanded scale the drop in load following successive ply failures becomes more apparent



Damage Progression Animation: UW BCs



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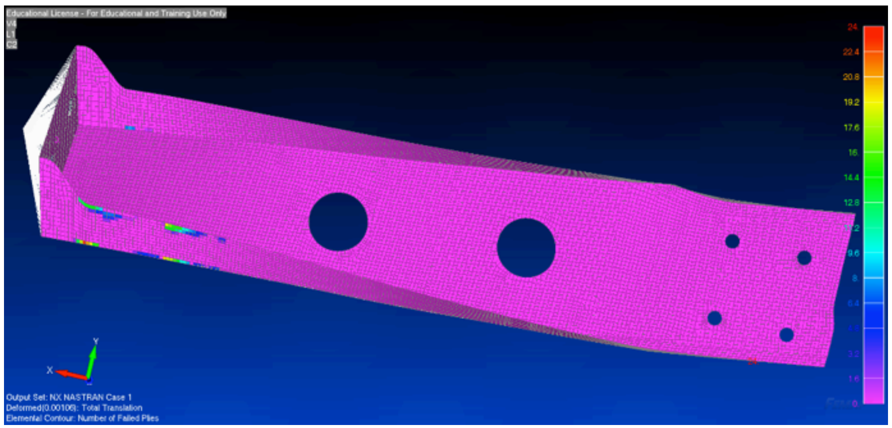
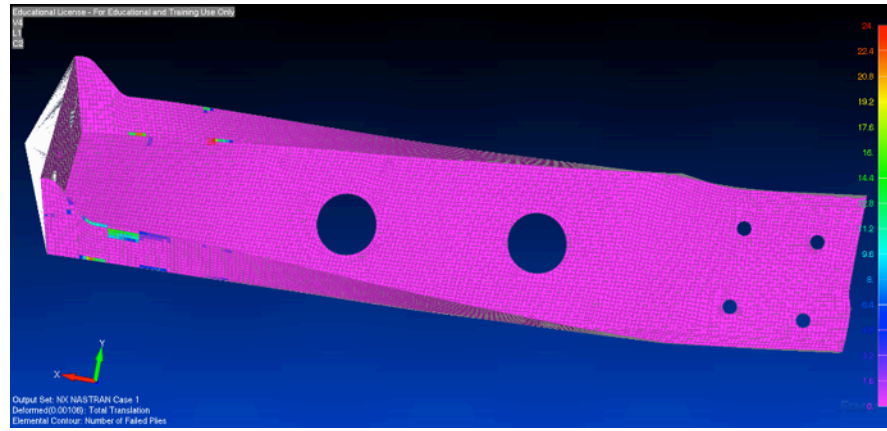
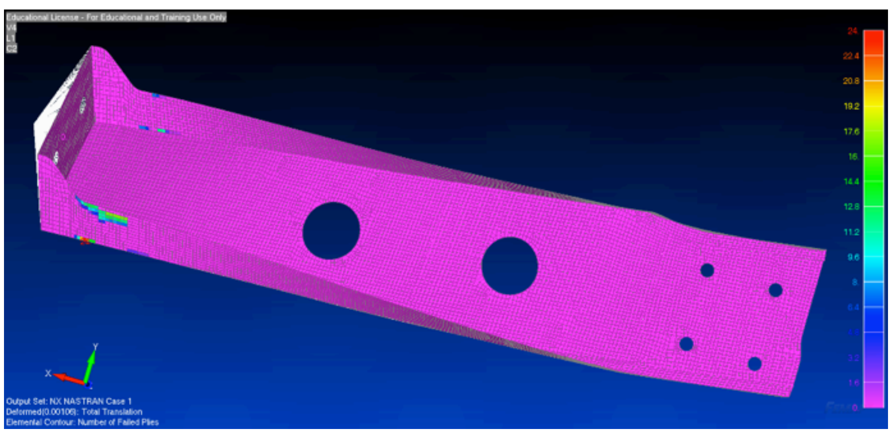
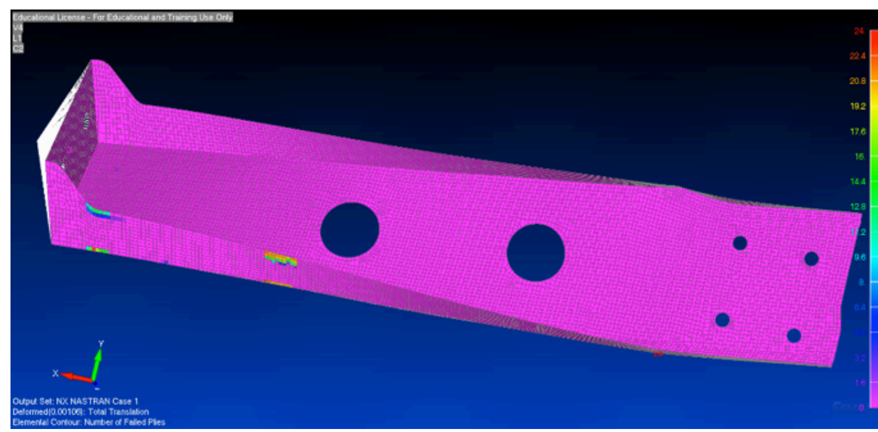
Damage at Failure Predicted During 4 Separate Analyses



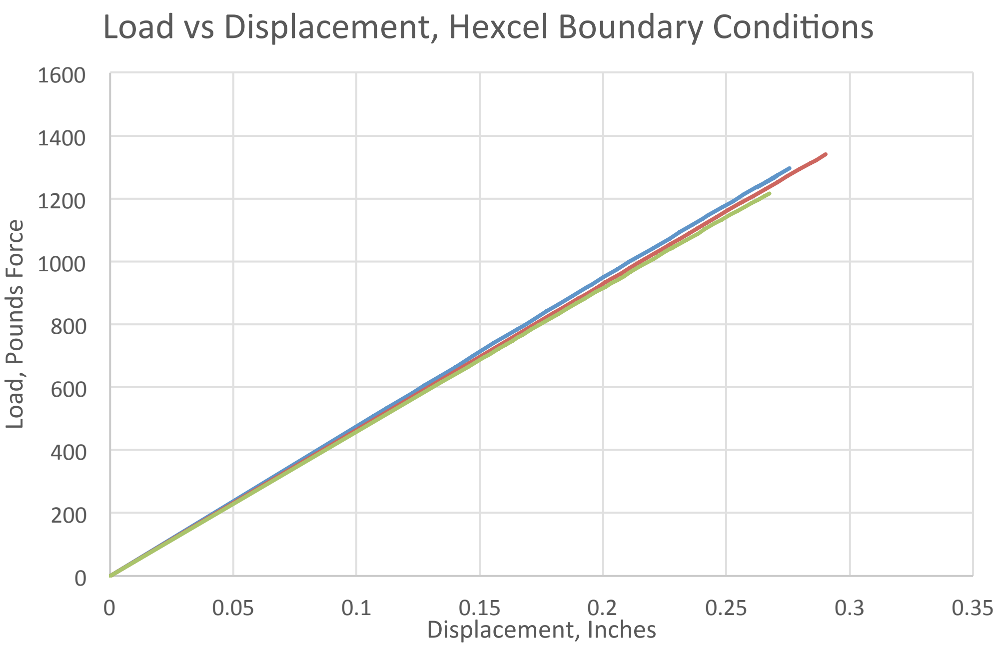




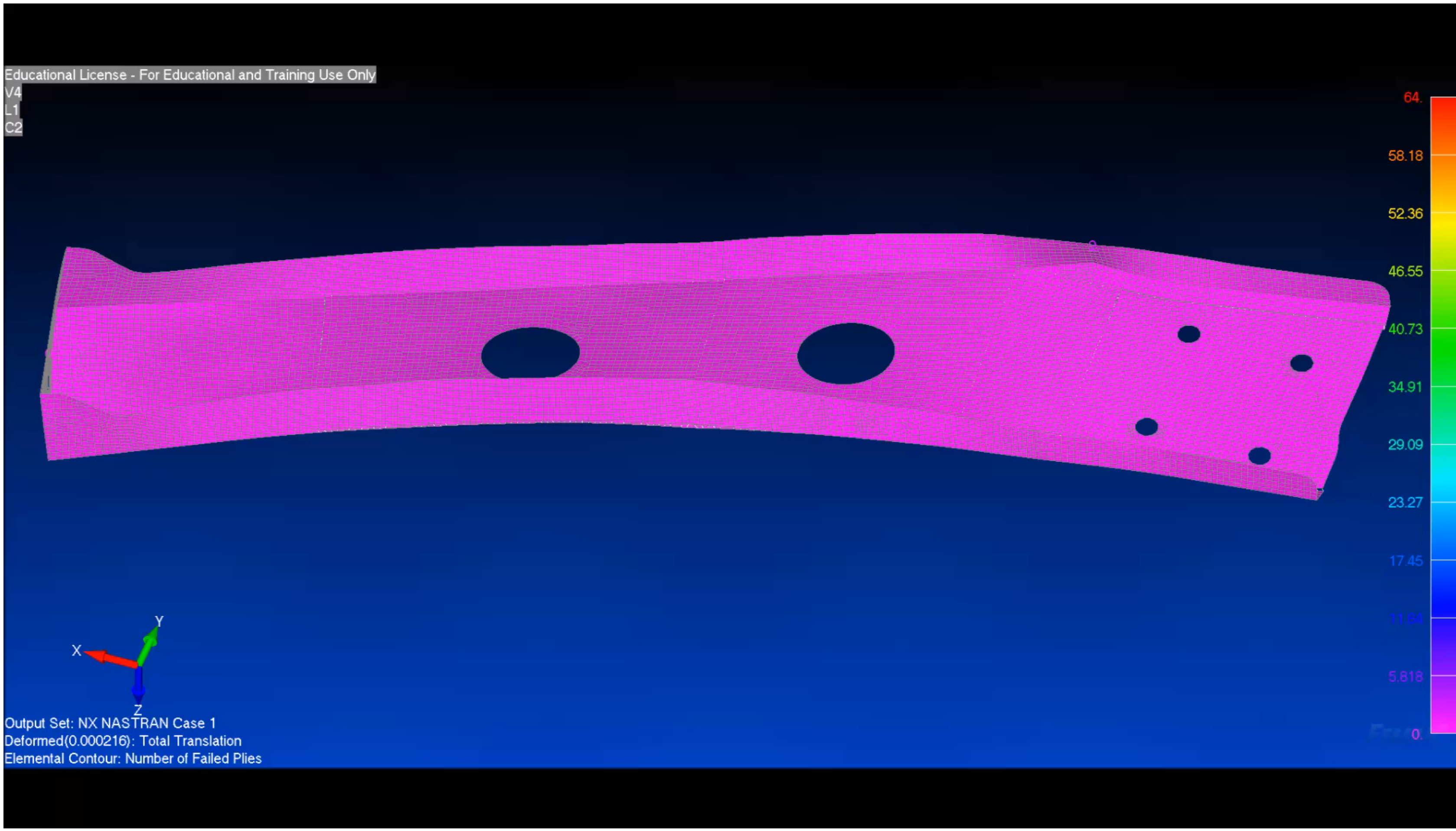


Results, Hexcel BCs

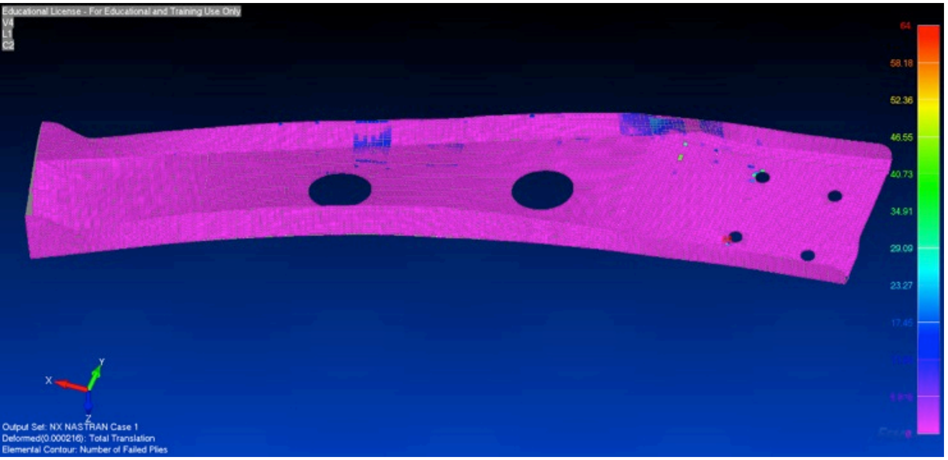
Analysis	Number of Failures	Load at Failure	Time
1	3186	1295.39	25 H, 13 M
2	2835	1339.72	22 H, 35 M
3	2337	1216.54	18 H, 40 M

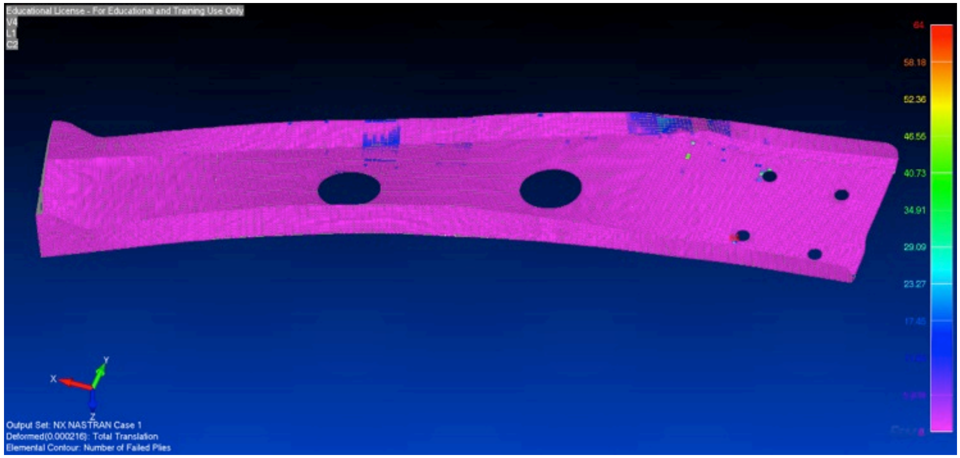


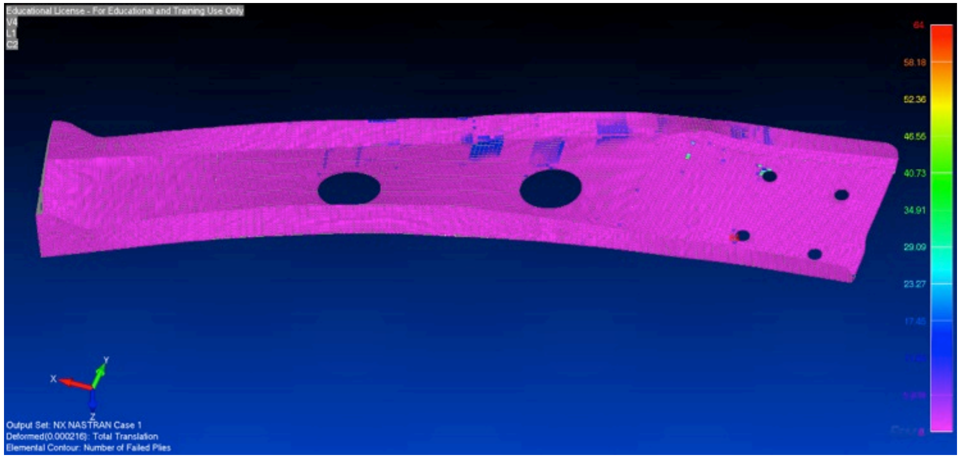
Damage Progression Animation: Hexcel BCs



Damage at Failure Predicted During 3 Separate Analyses







Next Steps

- Additional Analyses Based on UW Boundary Conditions
- Additional Analyses Based on Hexcel Boundary Conditions
- Analyses using Femap/NASTRAN Nonlinear Solver (does not support failure predictions however)
- Redefine Final Fracture Condition?

Summary and Conclusions

Thank You!